ARL-FLIGHT-MECH-R-187 AR-005-639

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

AERONAUTICAL RESEARCH LABORATORY

MELBOURNE, VICTORIA

Flight Mechanics Report 187

F-111C FLIGHT DATA REDUCTION AND ANALYSIS PROCEDURES

by

M.I. Cooper
J.S. Drobik
C.A. Martin

A-1

Approved for public release

DECEMBER 1990

AR-005-639

DEPARTMENT OF DEFENCE
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
AERONAUTICAL RESEARCH LABORATORY

Flight Mechanics Report 187

F-111C FLIGHT DATA REDUCTION AND ANALYSIS PROCEDURES

by

M. I. COOPER
J. S. DROBIK
C. A. MARTIN

SUMMARY

A series of flight trials was performed on the F-111C aircraft at the RAAF's Aircraft Research and Development Unit in February and October 1987. Data obtained from the tests were analysed at the Aeronautical Research Laboratory to determine the aircraft aerodynamic and control derivatives. This report describes the methods and computer programs which are used to process and analyse the flight test data. Data handling procedures, pre-analysis flight data processing and the methods used to make corrections to air sensor measurements are described. Although the test programme was conducted on a F-111C aircraft, with minor alterations the computer programs and procedures can be used for other aircraft test programmes.

Postal Address : Director, Aeronautical Research Laboratory,
506 Lorimer Street, Fishermens Bend, Victoria, 3207, Australia.

Contents

List of Tables

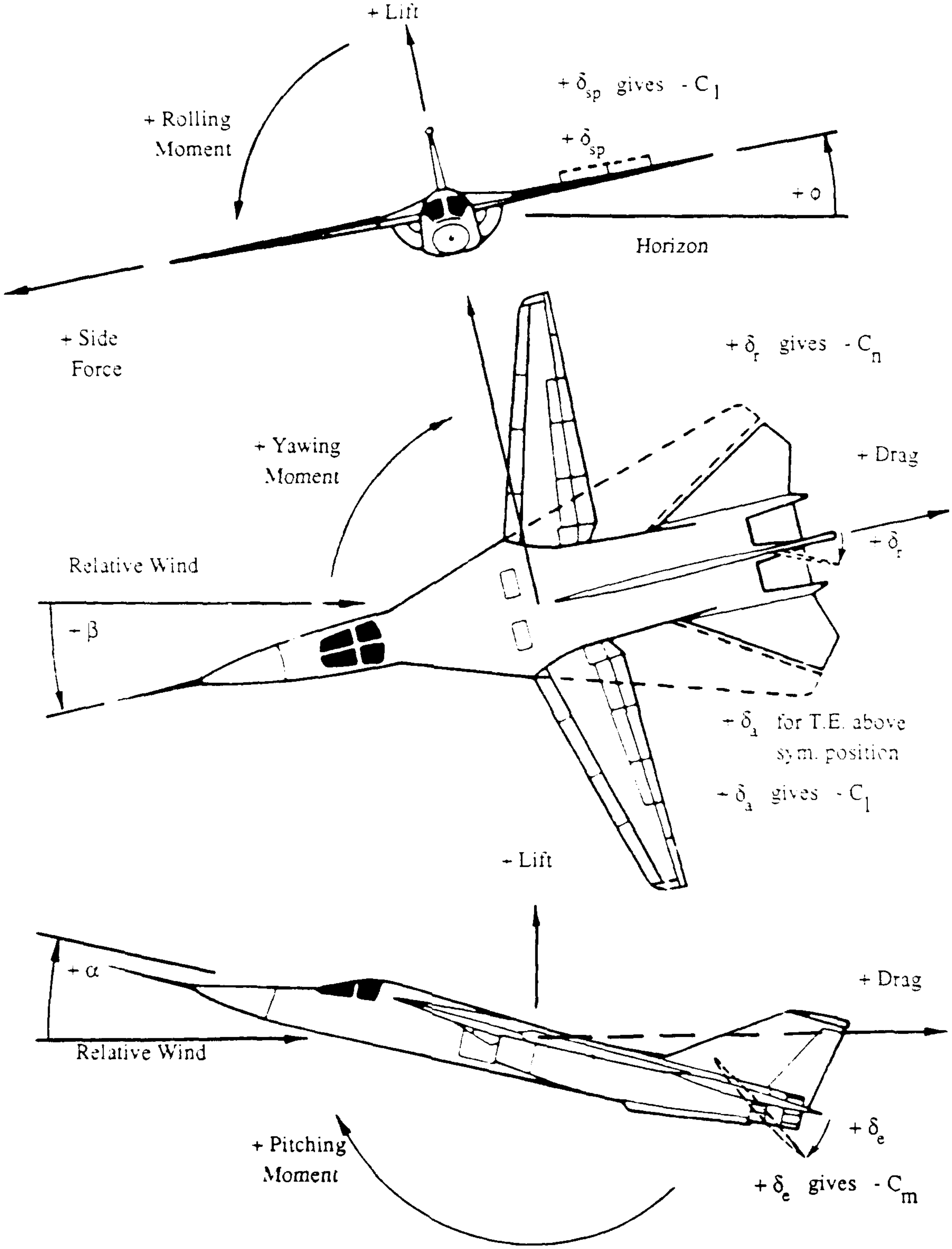
List of Figures

Notation

a	Coefficient of linear equation
a_n, a_x, a_y	Normal, longitudinal and lateral acceleration, g
b	y-intercept of linear equation for curve fitting
C_l	Rolling moment coefficient
C_n	Yawing moment coefficient
C_Y	Side force coefficient
c	Reference chord
c.g.	Centre of gravity as a fraction of reference chord
CADS	Central Air Data System
g	Gravitational acceleration
H	Altitude
I_{xx}, I_{yy}, I_{zz}	Moments of inertia about roll, pitch and yaw axes
I_{xz}	Cross product of inertia
K_α, K_β	Flow amplication factors for angle-of-attack and sideslip
M	Mach number
m	Mass of aircraft
$NBTU$	Nose Boom Transducing Unit
p	Roll rate
q	Pitch rate
$\bar{q}$	Dynamic pressure
r	Yaw rate
R	Degrees per radian (57.2958)
S	Reference area
T	Thrust
TACT	Transonic Aircraft Technology
u	Control vector
V	Velocity
x	State vector
x_{a_y}, x_β	Longitudinal instrument offsets from c.g.
y_{a_y}	Lateral instrument offsets from c.g.
z	Measured observation vector
z_{a_y}, z_β	Vertical instrument offsets from c.g.
α	Angle of attack
β	Angle of sideslip
δ	Control deflection
δ_a	Aileron deflection $(\frac{\delta_{stab_R}+\delta_{stab_L}}{2})$
δ_r	Rudder deflection
δ_{sp}	Spoiler deflection
δ_{stab}	Stabilator deflection
ε	Error between model and flight data
θ	Pitch angle
Λ	Wing sweep angle
ϕ	Roll angle

Subscripts

CM	Crew module instrument	
L	Left (port)	
m	Measured quantity	
NBTU	Nose Boom Transducing Unit	
$\dot{\alpha}, \dot{\beta}, p, q, r$	Rate derivatives with respect to indicated quantity	(per degree/sec)
R	Right (starboard)	
α, β	Static derivatives with respect to indicated quantity	(per radian)
$\delta, \delta_a, \delta_r, \delta_{sp}$	Control derivatives with respect to indicated quantity	(per degree)
STANDARD	Standard aircraft baseline configuration	
0	Bias	



Force and Moment Sign Convention (Stability Axes)

1 Introduction

Models of aircraft flight dynamics are used for a range of applications. for example, the analysis of aircraft behaviour, for aircraft design, and for driving flight simulators. Part of this modelling procedure involves the estimation of the aerodynamic stability and control derivatives from various sources such as empirical, wind tunnel and flight tests. This report describes the methods and computer programs which are used to process and analyse data obtained from a flight test programme conducted on a General Dynamics F-111C aircraft. Data handling procedures, pre-analysis flight data processing and the methods used to make corrections to air sensor measurements are described. Data extraction is carried out on a VAX 750 computer using Fortran programs developed at the Aircraft Research and Development Unit (ARDU). Data processing and analysis is carried out on the ARL ELXSI 6400 computer using Fortran programs either acquired or specifically developed at ARL. Data presentation is carried out on an IBM PS2 personal computer using a computer program written in Pascal.

Flight testing of the aircraft was carried out at ARDU in 1987. Data from the programme has been used to validate a comprehensive flight dynamic model of the F-111C which was developed at ARL and this model will be used to upgrade the F-111C flight training simulator at RAAF Base Amberley.

2 Test Aircraft and Instrumentation

The F-111C test aircraft A8-132, illustrated in Figure 1, was extensively modified under ARDU Test Schedule 1650 with flight test quality instrumentation and data recording equipment. This equipment known as the Airborne Flight-Test Recording and Analysis System (AFTRAS) provides on-board digital magnetic-tape recording and telemetry information for real-time flight test monitoring. The instrumentation was developed for use for store-carriage and release tests and for the flight dynamic measurements and is capable of measuring 200 measurands at a sampling rate of 60 per second. Special equipment was developed for recording, and for manual adjustment of the pitch and roll adaptive gain values. Because of insufficient time, the instrumentation required to monitor other parts of the adaptive control system was not installed. Similarly, the instrumentation for monitoring engine parameters required for detailed performance measurements was not fitted. These parts of the instrumentation were not required for the estimation of the aerodynamic coefficients, but were required for the related investigation of the adaptive control system behaviour and aircraft performance characteristics.

The Nose Boom Transducing Unit which was used for the second phase of the trials, was constructed by the Advanced Engineering Laboratory (AEL) Salisbury and was designed to provide high quality measurements of pitot pressure, angle-of-attack, angle-of-sideslip and linear accelerations parallel and normal to the local airflow direction. The unit was modelled on the CONRAC Nose Boom Instrumentation Unit (NBTU) Model 25126F, developed by the USAF for flight dynamic performance measurements. The NBTU is shown in Figure 2 and a detailed description of the assembly is given in Reference [1].

A list of the instrumentation channels (measurands), including their ranges and accuracies, which are used for the flight dynamic analysis is given in Table 1. These channels were recorded at a rate of 60 samples per second using the AFTRAS system.

The measurement of the pressure error corrections for the NBTU was carried out by ARDU as part of the Test Schedule 1691. Details of these measurements are presented in Appendix D.

3 Flight Test Programme

An outline of the flight test programme is presented below. Full details of the programme are contained in the flight data analysis reports (References [2] to [7]).

3.1 Test Points

The flight test programme was carried out in two phases. The matrix of test points covered in Phase 1 and Phase 2 is given in Table 2. The first phase covered 75 test conditions representing combinations of wing sweep, altitude and Mach number. At each test point two longitudinal and two lateral manoeuvres were performed. The flow angles in this phase were obtained from tranducers in the aircraft's standard Central Air Data System (CADS). For the second phase of the programme a Nose Boom Transducing Unit (NBTU) was available for the measurement of the angles of attack and sideslip. A number of Phase 1 test point manoeuvres were repeated in Phase 2 to compare the accuracy of the results using the aircraft system (CADS) and the NBTU system for measurements of angle of attack and angle of sideslip. The remaining tests were made at Mach numbers between those tested in Phase 1 to provide a more comprehensive data coverage. The total test program required 24.6 test hours of flying.

3.2 Test Manoeuvres

The following manoeuvres were performed at each test point.

1. accurate trim
2. pitch input where the stick is pulled back (1 to ≈ 2 'g') then pushed forward to neutral and the aircraft allowed to damp in pitch.
3. trim

4. pitch input where the stick is pushed forward (1 to $\approx$ 0 'g') then pulled back to neutral and the aircraft allowed to damp in pitch.
5. accurate trim
6. rudder step input to left followed by aileron doublet to achieve $\approx \pm 30°$ bank angle. Rudder and aileron released together.
7. trim
8. manoeuvre 6. repeated but rudder input to right and opposite roll applied
9. trim

These specified manoeuvres are designed to give an aircraft response which is optimum for the determination of stability and control derivatives using the techniques described in Section 4. Advice provided by NASA Dryden test personnel from experience with the F-111A TACT aircraft, indicated that large rapid control inputs were necessary to provide large amplitude excitation of the natural modes of the aircraft with the automatic flight control system engaged.

Manoeuvres were also flown with the aircraft in the landing and take off configurations. These cases are summarised in Table 3.

Supplementary manoeuvres were performed to enhance the prediction capability of the validated ARL flight dynamic model and for use as test manoeuvres for the F-111C flight training simulator. These included:

1. longitudinal roller-coaster manoeuvres
2. lateral oscillatory manoeuvres
3. dutch rolls
4. steady heading sideslips
5. longitudinal trims

The manoeuvres and the flight conditions at which they were performed are summarised in Table 4.

3.3 Flight Control System Status

The tests were conducted with the flight control system in the normal mode and with the system gains determined by the normal adaptive mode gain changer. However, when rapid control inputs were applied at some flight conditions, motion due to the adaptive mode was superimposed on the natural motion of the aircraft. The problem of adaptive mode ringing was overcome by pumping the stick and driving the control system gains down to a level where the aircraft natural response dominated the motion.

4 Flight Data Processing and Analysis

Flight data processing and analysis was carried out in the order shown in Figure 3. The procedures used, and the software developed and acquired for this purpose are summarised in this section. Details of the procedures are given in the Appendices. Figures 4 and 5 list the names of the input and output files used by various procedures and lists the analysis programs.

A significant aspect of the programme involved the managment of large amounts of data. Approximatley 10.5 million data points were acquired in this programme, being the aggregate of 33 measurands sampled at 60 samples per second for test manoeuvres totaling 46 seconds at each of the 162 test conditions. Approximately 20 hours of CPU time and 15 Megabytes of disk storage on a high speed mainframe computer was required to analyse the cases for a complete Mach number range at one sweep angle and one altitude. A total of 6 sweep angles was tested at 5 different altitudes in the clean configuration. Additional measurements were also made in the take off and landing configurations.

4.1 Data Extraction

The AFTRAS flight data system provides organised procedures for accessing selected channels, for applying calibrations to give engineering units, and for formatting the data for subsequent analysis. Calibrations are stored as polynomial coefficients against the date of calibrations and are appended to the data files obtained from each flight. Details of these procedures are given in Reference [8]. The procedures are carried out using program EXTRACT which can be run on the ARDU or ARL VAX computers. Appendix A describes the EXTRACT procedures in detail and through the use of an example, indicates the information which has to be provided and the form of the data extracted.

The input data required for use by the parameter estimation techniques needs additional processing to provide the required data format and also to apply further measurement error corrections. This processing stage is carried out within program FDP on the ARL ELXSI computer and is described in detail in Appendix C. The corrections are required :

1. to compensate the airspeed, Mach number and altitude for pressure errors and compressibility effects at the pitot-static sensor locations
2. to apply time shifts to the time history records to compensate for instrument signal conditioning and recording lags
3. to calculate pitch and roll control deflections from the measured stabilator deflections
4. to calculate weight, c.g. and moments of inertia information from the fuel tank contents data

4.2 Aircraft Mass Characteristics

Accurate information is required of all-up weight, horizontal, vertical and lateral centre of gravity position and inertia properties for the analysis of dynamic manoeuvres. This information is used to convert the aerodynamic derivatives into non-dimensional coefficients, to provide references for instrumentation and sensor position and to allow valid comparisons of the derivatives obtained from different flights where the mass characteristics, especially the C of G position, may be different. Aerodynamic moment data obtained from wind tunnel tests are usually referenced to a given C of G position and an adjustment for the actual flight test positions must be included if a valid comparison is to be made.

Procedures for determining the mass characteristics for the test aircraft A8-132 were as follows:

- Aircraft was weighed to establish baseline data.
- Fuel calibration tests were conducted.
- Software was developed using manufacturers data to calculate mass characteristics and adjustments made to reflect weight and fuel calibration results.
- At each test point the indicated fuel tank contents were recorded.

4.2.1 Aircraft Weighings

The aircraft was weighed in accordance with standard RAAF weighing procedures. Tables 5 to 10 show the results for the various configurations which form the baseline aircraft information. The change in weight and C of G for the aircraft with the NBTU fitted (Phase 2 flights) was derived from the information contained in Table 10.

4.2.2 Fuel Calibration

A fuel calibration was obtained by emptying the fuel tanks of all useable fuel and adding a known amount to the forward and aft tanks then recording the indicated and actual tank contents. During the flight test the aircraft loading and centre-of-gravity varied in accordance with the aircraft auto-fuel schedule, which is described in Appendix B. After take-off the aircraft would use all fuel in the wing and primary weapons bay fuel tanks before any flight test manoeuvres commenced. Prior to each test point the indicated foward and aft fuel tank contents were recorded on the pilots test card and, by applying the fuel calibration, an accurate calculation of C of G and AUW was made. Figure 6 shows a typical test card with relevant information highlighted. During the test manoeuvres, the aircraft weight was typically near 70,000 lb.

4.3 Instrumentation Time Lags

A procedure for identifying the relative time lags between instrumentation channels was developed at ARL and is documented in Reference [9]. This procedure also uses the maximum likelihood technique and was applied to a number of selected time histories to determine the lag parameters. The resulting parameters are given in Table 11 where a positive integer indicates n time samples ($n/60$ seconds) lagged with respect to the control deflection signals. The table shows that the NBTU signal for angle-of-attack leads the control deflection signals by two sample intervals, showing that this instrumentation has smaller signal delays than the Phase 1 instrumentation.

4.4 Calibration of α and β Flow Vanes Using Flight Path Reconstruction

In addition to determining the pressure error corrections to airspeed and altitude it is also necessary to determine the position errors (or calibration constants) for the angle-of-attack and angle-of-sideslip tranducers. In particular the aircraft CADS transducers are mounted close to the forward fuselage where local flow angles can differ substantially from the free-stream value. A Flight Path Reconstruction (FPR) method for determining these calibration constants is described in Reference [10].

The flight path reconstruction technique uses an extended Kalman filter to determine the calibration parameters relating the computed and measured output variables.

This method uses a combined parameter and state estimation technique and is based on using the kinematic equations of motion of a rigid body. Using longitudinal, lateral and normal accelerations and pitch, roll and yaw rates as inputs, the state variables, ie. the body axes velocities (u, v and w) and roll, pitch and yaw attitudes (ϕ, θ and ψ) are estimated. From these estimates, the output quantities, velocity, angle-of-attack, angle-of-sideslip, bank and pitch angle and altitude ($V, \alpha, \beta, \phi, \theta$ and h) are calculated and compared with measured values of the outputs. The calibration constants are adjusted along with instrument bias parameters to minimise these output errors.

As an example of the procedure consider the force equation in the Y body axis direction for a rigid aircraft (equation 5.8,2(b) Reference [11]).

$$\overbrace{Y}^{aerodynamic\ contribution} + \overbrace{mgCos\theta Sin\phi}^{gravity\ contribution} = \overbrace{m(\dot{v} + ru - pw)}^{inertial\ contribution} \ldots(1)$$

Forces in the X,Y and Z direction cannot be measured directly but use can be made of accelerometers. Dividing equation (1) by m

$$\frac{Y}{m} + gCos\theta Sin\phi = (\dot{v} + ru - pw) \ldots(2)$$

gives:

$$a_y + gCos\theta Sin\phi = (\dot{v} + ru - pw)...(3)$$

The above equation is a kinematic equation relating acceleration, velocity and displacement. Assuming small angles (< 10deg.), a relationship between the measured kinematic variables and angle of attack α and angle of sideslip β can be developed:

$$\alpha \simeq \frac{w}{V}, \beta \simeq \frac{v}{V} and \frac{u}{V} \simeq 1...(4)$$

Then dividing both sides of equation (3) by V gives :

$$\frac{a_y}{V} + \frac{g}{V}Cos\theta Sin\phi = \frac{\dot{v}}{V} + \frac{ru}{V} - \frac{pw}{V}...(5)$$

Substituting for α and β gives

$$\frac{a_y}{V} + \frac{g}{V}Cos\theta Sin\phi = \dot{\beta} + r - p\alpha...(6)$$

Rearranging equation (6) gives $\dot{\beta}$ in terms of other kinematic variables

$$\dot{\beta} = \frac{a_y}{V} + \frac{g}{V}Cos\theta Sin\phi - r + p\alpha...(7)$$

Now assuming that all of the variables on the right hand side can be measured with no scale factors or bias errors β, can be calculated by integration of equation (7)

$$\beta = \int (\frac{a_y}{V} + \frac{g}{V}Cos\theta Sin\phi - r + p\alpha) + constant...(8)$$

A comparison can be made between the measured value of sideslip β_m and the value calculated from equation 8 assuming a linear relationship between the local flow angle and the free stream value of the form:

$$\beta_m = K_\beta \beta_{actual} + b_\beta$$

From this comparison the scale factor K_β and bias b_β can be determined.

For a jet aircraft with no asymmetric flow, the constant of integration or the bias can be expected to be zero. A similar procedure is carried out with the Z force equation to determine an expression for angle of attack α.

The estimation software used for this purpose was developed for ARL under a research agreement with the University of Newcastle. (References [12] and [13]). Application of the method to the measured time histories gave estimates for the calibration constants for the CADS and NBTU angle-of-attack and angle-of-sideslip measurement systems. For the angle-of-sideslip sensor the calibration constant varied with Mach number. Values of between 1.49 and 1.60 (CADS) were used for Phase 1 and 1.06 and 1.20 (NBTU) for Phase 2.

The CADS angle-of-sideslip sensor which is located beneath the forward fuselage over estimated the true value by 50-60% indicating strong cross-flow in this region. The NBTU gave, as expected, more accurate estimates of angle-of-sideslip, over-reading by only approximately 10-20%. While some small variations occur in the angle of attack scale factor, K_α with Mach number and sweep angle, these variations are not well defined within the accuracy of the data and so constant values of 0.94 and 1.06 have been used for Phase 1 and Phase 2 respectively. An investigation into the effect of K_α variation showed that errors in K_α of 10 % resulted in an adjustment of typically 5 % in the major derivatives.

4.5 *A priori* Data from Model

A six degree of freedom flight dynamic model of the F-111C aircraft, as described in Reference [14], has been developed at ARL and includes representation of the flight control system. A comprehensive aerodynamic data base is used to obtain *a priori* or initial estimates of the aerodynamic stability and control derivatives. Configuration data and initial conditions are defined for each test point as described in Appendix G.

4.6 Parameter Estimation

A number of techniques have been developed in recent years for the estimation of aerodynamic derivatives from flight test measurements. These techniques generally use a statistical approach to the process of fitting a flight dynamic model to aircraft response time histories. The aerodynamic stability and control derivatives are then calculated from the coefficients of the flight dynamic model. For the F-111C data analysis, a Maximum Likelihood technique was used. A priori information for the Maximum Likelihood technique was obtained using the ARL six degree of freedom flight dynamic model and is described in Appendix G. The technique and associated computer program are described in References [15] and [16] and an example MMLE3 analysis is given Appendix H.

Within the range of flight conditions tested in the F-111C programme, it is assumed that the aircraft motion can be adequately represented by separate classical linear flight dynamic models for longitudinal and lateral motion. The longitudinal and lateral flight dynamic models, used for this purpose are derived assuming small disturbance motion and linear aerodynamic characteristics. The equations are presented in Appendix I and J.

The maximum likelihood technique uses a Newton-Raphson search algorithm to iterate to a converged solution. The program defines a cost function which is the weighted sum of the difference between the model prediction and measured time histories (see Figure 7). Convergence is declared when the cost function is less than a specified level.

The stabilator angle deflection was used as the input for the longitudinal manoeuvres and the rudder, differential stabilators and spoilers for the lateral manoeuvres. Note, spoilers only operate for cases with wing sweep less than 47°. The angle of attack, pitch rate and normal acceleration comprise the outputs for the longitudinal model. The angle of sideslip, roll rate, yaw rate and lateral acceleration comprise the outputs of the lateral model.

The derivatives used in the linear identification model and their importance are summarised in Figure 3. The derivatives can be divided into three categories. The static derivatives are fundamentally 'stiffness' parameters and the dynamic derivatives are 'damping' parameters. The analogy is drawn with a second order mass spring damper system. The control derivatives describe the forces and moments due to control surface deflections. Figure 9 compares the pitch response to an elevator input measured in flight with the response calculated from the estimated derivatives.

To assist the identification procedure, particularly for derivatives which make only a small contribution to the motion, *a priori* information can be used in the identification procedure. A facility exists to constrain selected parameters to either *a priori* values or to other model parameters. Constraints were used in the longitudinal model but not in the lateral model.

For the unconstrained parameters the estimation procedure calculates a measure of the estimation accuracy known as the Cramer-Rao bound. The interpretation of this quantity is given in Reference [15].

The results plotted for each aerodynamic derivative show an average value for this prediction error calculated from the data points on each plot, which can be used in conjunction with the observed repeatability to indicate the estimation accuracy. To account for the fact that the signal noise is bandwidth limited, the Cramer-Rao bound is factored by a multiple of 10 in accordance with the procedures described in Reference [16]. Two additional procedures were used prior to the application of the maximum likelihood technique to improve the quality and consistency of the measured time histories. These are discussed in Appendix H.

4.7 Curve Fitting of Derivative Results

It is planned that the data from these flight tests will be used to update the aerodynamic data base used in the RAAF's F-111C simulator. To correct the existing data-base, the new derivative information must be presented as variations with Mach number for each sweep and altitude. The approach which has been used is to relocate the model data curve to best fit the flight derivatives, therefore combining the general information from the flight tests and the detailed trends given by the model. The procedure used is shown in Figure 10. Details of this process are presented in Reference [17]. Details of the notation used to name analysis files is given in Appendix K.

5 Concluding Remarks

This report describes the steps involved in processing and analysing data from a flight test program on an F-111C aircraft to determine aerodynamic stability and control parameters. All stages in the process are described and details of the individual procedures are given in separate Appendices. Computer programs developed for the analysis are described and running instructions are provided. The programs and procedures can be used for other aircraft test programmes with minor alterations.

Acknowledgements

The authors of this report would like to thank the staff of ARDU for the instrumentation, flight test planning and for the conduct of the test programme.

The support received from Peter Gibbens, Shane Hill, Leon MacLaren, Rodd Perrin, Wim Dekkers and Justin Baker at ARL is also acknowledged.

References

[1] Department of Defence, Defence Science and Technology Organisation, Advanced Engineering Laboratory, Special Document AEL-0269-SD, Nose Boom Transducing Unit (NBTU), Installation, Operation and Maintenance Manual, June 1988.

[2] MACLAREN, L.D., MARTIN, C.A., COOPER, M.I., DROBIK, J.S., F-111C Longitudinal Aerodynamic Flight Data Analysis For Wing Sweeps of 16 deg. and 26 deg. ARL Flight Mechanics Report 181.

[3] MACLAREN, L.D., MARTIN, C.A., COOPER, M.I., DROBIK, J.S., F-111C Longitudinal Aerodynamic Flight Data Analysis For Wing Sweeps of 35 deg. and 45 deg. ARL Flight Mechanics Report 182.

[4] COOPER, M.I., MARTIN, C.A., DROBIK, J.S., GIBBENS, P.W., F-111C Longitudinal Aerodynamic Flight Data Analysis For Wing Sweeps of 50 deg. and 72.5 deg. ARL Flight Mechanics Report 183.

[5] DROBIK, J.S., MARTIN, C.A., COOPER, M.I., GIBBENS, P.W., F-111C Lateral Aerodynamic Flight Data Analysis For Wing Sweeps of 16 deg. and 26 deg. ARL Flight Mechanics Report 184.

[6] DROBIK, J.S., MARTIN, C.A., COOPER, M.I., GIBBENS, P.W., F-111C Lateral Aerodynamic Flight Data Analysis For Wing Sweeps of 35 deg. and 45 deg. ARL Flight Mechanics Report 185.

[7] DROBIK, J.S., MARTIN, C.A., COOPER, M.I., GIBBENS, P.W., F-111C Lateral Aerodynamic Flight Data Analysis For Wing Sweeps of 50 deg. and 72.5 deg. ARL Flight Mechanics Report 186

[8] ARDU AFTRAS Data User's Manual, 6 March 1985, RAAF ARDU.

[9] BLACKWELL, J., A Maximum Likelihood Parameter Estimation Program for General Non-Linear Systems, ARL Aerodynamics Technical Memorandum 392, January 1988.

[10] MARTIN, C.A. and COOPER, M.I., A Method for the In-Flight Calibration of Sideslip and Angle-of-Attack Flow Direction Vanes, ARL (Unpublished), June 1986.

[11] ETKIN, B., Dynamics of Atmospheric Flight.Wiley and Sons 1972.

[12] NORTON, J.P., De SOUZA, C.E., EVANS, R.J. and GOODWIN, G.C, Nonlinear Estimation Algorithms for Aircraft Flight Path Reconstruction, University of Newcastle, Department of Electrical and Computer Engineering, Technical Report EE8340, October 1983.

[13] De SOUZA, C.E. and GOODWIN, G.C., User's Guide for the Flight Path Reconstruction Programmes, University of Newcastle, Department of Electrical and Computer Engineering, Annex to EE8340, June 1986.

[14] COOPER, M.I., A Flight Dynamics Model of the F111-C Using the Simulation Language ACSL, ARL Aerodynamics Report 166, December 1985. (Confidential)

[15] MAINE, R.E. and ILIFF, K.W., User's Manual for MMLE3, a General FORTRAN Program for Maximum Likelihood Parameter Estimation, NASA Technical Paper 1563, 1980.

[16] MAINE, R.E. and ILIFF, K.W., Application of Parameter Estimation to Aircraft Stability and Control - The Output-Error Approach, NASA Reference Publication 1168, June 1986.

[17] BAKER, J., Graphical Presentation of F-111C Flight and Model Data, (Unpublished), August 1988.

[18] ARNEY, A.M., Using the General Purpose Output Program 'TRANS', ARL (Unpublished), July 1988.

[19] ARDU, Determination of the Pressure Error Correction For the F111C Aircraft, Technical Note Aero 80 (with Annex), 1987

[20] ESDU Airspeed Data for Performance Calculations. ESDU Data Item 69026, October 1969 (with Amendment A)

[21] PERRIN, R., Notes on The Application of Compatibility Checking Program COMPAT.HM and Parameter Estimation Program MMLE3 to Aircraft Flight Data, ARL (Unpublished), April 1986.

[22] DEKKERS, W., Extraction of Control Derivatives From a Flight Dynamics Simulation in Air-Path Axes Using ACSL, ARL (Unpublished), May 1986.

Appendix A - Extracting Data From Flight Test Tapes

The AFTRAS program EXTRACT is used to extract flight test data recorded on magnetic tape. After further processing by program LISTPARM, a list of parameters and associated values in engineering units are outputed in ASCII form. Each channel has a recording width of 4000 computer units and calibrations were conducted to establish the relationship between computer units and engineering units. A typical calibration is shown in Figure A1. Extraction of data at ARL is carried out on the EDS VAX 750 computer and the procedures involved are best illustrated through the use of an example and reference to Figure A2.

For the purpose of this exercise the manoeuvre selected occured on the first flight of the second phase of tests and is event 72. From the flight test report it is established that event 72 commenced at approximately 1040.0 seconds and finished at about 1109.0 seconds. From Table A1 it can be seen that the data are stored on ARL tape 1153 and the data are from the first flight of a possible 3 on this tape.

After logging onto the VAX 750 computer at ARL and with tape 1153 mounted on drive MTB0:, the following commands are given to assign devices: (note that all user responses are prefixed by a > symbol)

```
> mount /foreign/blocksize=15100 mtb0:

%MOUNT-I-WRITELOCK, volume is write locked
%MOUNT-I-MOUNTED,  mounted on _MTB0:
> ass mtb0: for001
> ass mtb0: for002
> ass mtb0: tape
```

Set default directory to [ae_drobik.aftras.vax.indata] and create the data input file P2F1E72.IN. This files contains the following details of the data to be extracted:

- The number of channels to be extracted (33)
- Time interval (0.01667 or $\frac{1}{60}$th of a second)
- Start of extraction (1040 seconds)
- Finish of extraction (1109 seconds)
- Channels and calibration versions to be selected (BI-170 calibration 4 to BI-031 calibration 1)

Shown below is file P2F1E72.IN

```
33   0.01667
1040.00     1109.000
BI 170  4
BI 171  4
BI 172  5
BI 173  2
BI 174  3
BI 175  3
BI 160  8
BI 201  7
BI 184  8
BI 023  1
BI 025  2
BI  40  4
BI 176  1
BI 177  1
BI 214  4
BI 215  4
BI  39  4
BI  41  1
BI  55  1
BI  43  2
BI  44  3
BI  45  2
BI 178  1
BI  53  2
BI  54  2
BI 238  5
BI 190  8
BI 195  8
BI 237  5
BI 188  4
BI 166  1
BI 028  1
BI 031  1
```

Table A2 lists the relevant channels in the order to be extracted (1 to 33) and gives the calibrations to be used. The order of the extracted channels is important and several points need to be considered when extracting data:

- Channel 7 should be selected according to the altitude of the case considered. For example BI-164-7 would be selected for a phase 1 40000 feet case.

- Channel 8 should be selected according to the Mach number of the case considered For example BI-202-8 would be selected for a phase 2 Mach 1.2 case.
- Channels 10 and 11, the angle of attack α and angle of sideslip β should be selected according to the phase. BI-237 and BI-188 for phase 1 CADS α and β, or BI-023 and BI-025 for phase 2 NBTU α and β.
- Phase 1 flights need only the first 28 channels to be extracted.
- Phase 2 flights have a total of 33 channels with NBTU α and β signals being selected in channels 10 and 11.
- For phase 2 flights channel 31 must contain the crew module accelerometer BI-31-01 signal. The output is in computer units and a calibration is applied during the flight data processing stage. If this channel is to be used instead of the C of G normal accelerometer (phase 2 flights 2 and 3) there is no need to place this signal in channel 1 because the selection of normal accelerometer to be used is carried out in the FDP stage.

Set default directory to [ae_drobik.aftras.vax.extract] and run command file EXTRACT.COM as shown below:

```
> set def [ae_drobik.aftras.vax.extract]
> list extract.com

$ set noverify
$ WRITE SYS$OUTPUT "             AFTRAS EXTRACT PROGRAM "
$ WRITE SYS$OUTPUT " "
$ WRITE SYS$OUTPUT "NB. Filenames fully qualified eg. [twp.ts1672]fred.dat"
$ INQUIRE q4 "ENTER THE MAG TAPE DRIVE e.g. MTAO: "
$ INQUIRE Q1 "ENTER THE INput  filename (.in1)         "
$ inquire Q2 "ENTER THE OUTput WORKING filename (.ou1) "
$ inquire q3 "Enter flight number of the file  on the archive tape (1-3)
 "
$ ru [ae_drobik.AFTRAS.vax.extract]EXTRACT/PARAMETER=('Q1','q2','q3','q4')
$ WRITE SYS$OUTPUT " no Batch Job submitted"
$ WRITE SYS$OUTPUT " - output logfile in your root directory "
$ EXIT
```

Shown below are the commands and responses to commence the extract and rewind the tape on MTB0:

```
> ru extract
F111C EXTRACT PROCESSING PROGRAM
```

```
Enter file code name, (eg:P3F2E101) :: > P2F1E72
Enter the tape sequence No. :: > 1

Infile=[-.INDATA]P2F1E72.IN
Outfile=[]P2F1E72.OUT
   READING ARCHIVE MAG TAPE
READ CALIBRATION FILE, NOW CHECKING INDATA
   ACCEL VERT "G"      BI-    170-       4
   ACCEL LAT  "G"      BI-    171-       4
   ACC LNG CG "G"      BI-    172-       5
   PITCH RATE DEG/SEC  BI-    173-       2
   ROLL RATE  DEG/SEC  BI-    174-       3
   YAW RTE CG DEG/SEC  BI-    175-       3
   HPF < 5K    FEET    BI-    160-       8
   MACH <.7  MACH      BI-    201-       7
   CAS FINE T KCAS     BI-    184-       8
   NBTU ALPHA DEGREES  BI-     23-       1
   NBTU BETA  DEGREES  BI-     25-       2
   STAB RH   DEGREES   BI-     40-       4
   PTCHACC CG  RAD/SEC BI-    176-       1
   ROLLACC CG RAD/SEC  BI-    177-       1
   ADI PITCH  DEGREES  BI-    214-       4
   ADI BANK   DEGREES  BI-    215-       4
   STAB LH    DEGREES  BI-     39-       4
   RUD POSN   DEGREES  BI-     41-       1
   RPEDAL POS INCHES   BI-     55-       1
   SPL LH O/B DEGREES  BI-     43-       2
   SPL RH O/B DEGREES  BI-     44-       3
   WNGSWPXDCR DEGREES  BI-     45-       2
   YWANG ACC  RAD/SEC  BI-    178-       1
   STK POS LG INCHES   BI-     53-       2
   STK POS LT INCHES   BI-     54-       2
   AOACADS-VE DEGREES  BI-    238-       5
   ALT CRSCAD FEET     BI-    190-       8
   CADS M CSE MACH     BI-    195-       8
   AOACADS+VE DEGREES  BI-    237-       5
   BETA CADS  DEGREES  BI-    188-       4
   CM ACC VRT "G"      BI-    166-       1
   ACC-X NBTU "G"      BI      28-       1
   NBTU A TMP DEGREES CBI-     31-       1
FORTRAN STOP
```

```
> SET MAG/REW MTBO:
```

A binary file of calibrated measurands in engineering units has now been created. This file has to be converted to ASCII code and transfered to the ELXSI 6400 computer for pre analysis processing. The program used for this purpose is called LISTPARM and is invoked from the directory [ae_drobik.aftras.vax.listparm]. Shown below are the commands and responses to run LISTPARM:

```
> RU LISTPARM

                    AFTRAS LIST PARAMETERS PROGRAM
                        version 2.1  july 85
                 AIRCRAFT RESEARCH AND DEVELOPMENT UNIT

PLEASE ENTER AFTRAS OUT FILENAME
> [-.EXTRACT]P2F1E72.OUT


TYPE 1 IF PRINTING BY EVENTS,
     2 IF PRINTING AT TIME INCREMENTS,
     3 IF PRINTING AVERAGES BETWEEN CONSECUTIVE EVENTS
     4 IF PRINTING 'ABOUT' EVENTS
     5 IF PRINTING ENTIRE FILE CONTENTS
     6 OUTPUT DEVICE IS :  SCREEN   , SELECT TO CHANGE
     7 CHANGE OUTPUT MEASURANDS
     8 TO FINISH
> 6
TYPE 1 IF PRINTING BY EVENTS,
     2 IF PRINTING AT TIME INCREMENTS,
     3 IF PRINTING AVERAGES BETWEEN CONSECUTIVE EVENTS
     4 IF PRINTING 'ABOUT' EVENTS
     5 IF PRINTING ENTIRE FILE CONTENTS
     6 OUTPUT DEVICE IS :  PRINTER  , SELECT TO CHANGE
     7 CHANGE OUTPUT MEASURANDS
     8 TO FINISH
> 5
FORTRAN STOP
```

Output from program LISTPARM is written to the file LISTPARM.DAT and this file is renamed to identify the particular case extracted eg. P2F1E72.DAT. This file is copied to the ELXSI by logging onto the ELXSI and using the netcopy command.

```
sethost edsvax
netcopy 'edsvax"ae_drobik"::[ae_drobik.aftras.vax.listparm]P2F1E71.dat
```

Flight data is now in ASCII format on the ELXSI and can be plotted using programs TRPLOT and TRANS. Reference [18] details the TRANS plotting program. TRPLOT converts ASCII data to ELXSI binary in a format suitable for TRANS and is run by:

```
> TRPLOT
  INPUT DATA FILENAME = > P2F1E72.DAT
  Read in VBLES etc---beginning numerical data
  Finished with data--TRFINI then end
  Fortran program executed STOP statement 0
```

Now run TRANS to create a device independent metafile plot file.

```
> TRANS
[TRANS version date 11-MAR-86]

I/P FILENAME = plots
   TS     1691     01          A08B-132          006

I/P FILE RECORDED ON 27-Jul-90   AT 09:53:54

INTEGN INT =  .0000E+00; RUN CPU TIME =  25.84 SEC.

TIME FROM 4.5800E+02 TO 4.9094E+02 IN STEPS OF 1.6670E-02

> PLS

IS GRAPHICS OUTPUT TO SCREEN REQUIRED :
> N
[PLS/O Output, for this run, going to DSK:plots.PL6 ]
STRIP PLOTS :

BLKS
> AV

TO SPECIFY NO. OF X UNITS/INCH, TYPE 0 FOR X
LENGTH OF AXES IN INCHES; X, Y =
> 10,5

ARE SYMBOLS REQRD FOR PLOTS :
> N
```

```
LINE KEY (0 GIVES DEFAULT) =
> 0

> goe
** RUNNING **
> *exi
```

A metafile PLOTS.PL6 has now been created and can be viewed using a metafile translator on any graphics device. Any channel can be plotted out at the ARL computer center. The file is renamed and plotted using the following instructions:

```
> COPY PLOTS.PL6 PLT.P2F1E71
> PLOT.ZT8 PLT.P2F1E72 PICNO=  1 FRAME=534,267
> PLOT.ZT8 PLT.P2F1E72 PICNO= 31 FRAME=534,267
```

Table A1: **Data Storage**

Phase 1 Flights				
Flight No.	Serials	ARDU Tape (segment)	ARL Tape (segment)	Comments
1	Shake 1	RDUVX2(1)	1043(1)	Shake down flight 1
2	Shake 2	RDUVX3(1)	1044(1)	Shake down flight 2
3	1,2	RXWX2(1)	1045(1)	
4	3,4	RXWX2(2)	1045(2)	
5	5,6,7	RDUVX4(1)	1046(1)	
6	10,11	RDUVX4(2)	1046(2)	
7	8,9	RDUVX4(3)	1046(3)	
8	12,13	RDUVX2(2)	1043(2)	
9	14,15	RDUVX2(3)	1043(3)	
10	16	RDUVX3(2)	1044(2)	
11	18,17	RDUVX3(3)	1044(3)	
12	18 repeat	RDUVX5(1)	1129(1)	
13	16 repeat	RDUVX5(2)	1129(2)	
14	17 repeat	RDUVX5(3)	1129(3)	
Phase 2 Flights				
Flight No.	Serials	ARDU Tape (segment)	ARL Tape (segment)	Comments
1	1 to 10	JD01(1)	1153(1)	
2	11 to 16	JDO1(2)	1153(2)	Normal accelerometer at CofG unavailable, use accelerometer in crew module
3	16,17,18,29,30,31	JD02(1)	1067(1)	
4	21 to 26,31	JD02(2)	1067(2)	
5	27,28,33,37	JD04(1)	1182(1)	
6	19,20,34,35,36,2 to 7	JDO4(2)	1182(2)	
7	27,28,33,37	JDO4(3)	1182(3)	

Table A2: **Instrumentation Calibrations**

Channel	No.	Order	Channel Calibration Number	
			Phase 1	Phase 2
acceleration vert.	170	1	4 4 4 4 4 4 4 4 4 4 4 4	4 4 4 4 4 4 4
acceleration lat.	171	2	4 4 4 4 4 4 4 4 4 4 4 4	4 4 4 4 4 4 4
acceleration long.	172	3	4 4 5 5 5 5 5 5 5 5 5 5	5 5 5 5 5 5 5
Pitch rate	173	4	2 2 2 2 2 2 2 2 2 2 2 2	2 2 2 2 2 2 2
Roll rate	174	5	3 3 3 3 3 3 3 3 3 3 3 3	3 3 3 3 3 3 3
Yaw rate	175	6	3 3 3 3 3 3 3 3 3 3 3 3	3 3 3 3 3 3 3
Height < 5 k	160	7	7 7 7 7 7 7 7 7 7 7 7 7	8 8 8 8 8 8 8
Mach < 0.7	201	8	6 6 6 6 6 6 6 6 6 6 6 6	7 7 7 7 7 7 7
CAS fine	184	9	6 6 6 6 6 6 6 6 6 6 6 6	8 8 8 8 8 8 8
AoA CADS +ve	237	10	4 4 4 4 4 4 4 4 4 4 4 4	5 5 5 5 5 5 5
Beta CADS	188	11	4 4 4 4 4 4 4 4 4 4 4 4	4 4 4 4 4 4 4
Right stab	040	12	4 4 4 4 4 4 4 4 4 4 4 4	4 4 4 4 4 4 4
Pitch acceleration	176	13	1 1 1 1 1 1 1 1 1 1 1 1	1 1 1 1 1 1 1
Roll acceleration	177	14	1 1 1 1 1 1 1 1 1 1 1 1	1 1 1 1 1 1 1
ADI pitch	214	15	4 4 4 4 4 4 4 4 4 4 4 4	4 4 4 4 4 4 4
ADI bank	215	16	4 4 4 4 4 4 4 4 4 4 4 4	4 4 4 4 4 4 4
Left stab	039	17	3 3 3 3 3 3 3 3 3 3 3 3	4 4 4 4 4 4 4
Rudder position	041	18	1 1 1 1 1 1 1 1 1 1 1 1	1 1 1 1 1 1 1
Rudder pedal posn.	055	19	1 1 1 1 1 1 1 1 1 1 1 1	1 1 1 1 1 1 1
Spoiler LH O/B	043	20	2 2 2 2 2 2 2 2 2 2 2 2	2 2 2 2 2 2 2
Spoiler RH O/B	044	21	3 3 3 3 3 3 3 3 3 3 3 3	3 3 3 3 3 3 3
Wing sweep	045	22	2 2 2 2 2 2 2 2 2 2 2 2	2 2 2 2 2 2 2
Yaw acceleration	178	23	1 1 1 1 1 1 1 1 1 1 1 1	1 1 1 1 1 1 1
Long. stick posn.	053	24	2 2 2 2 2 2 2 2 2 2 2 2	2 2 2 2 2 2 2
Lat. stick posn.	054	25	2 2 2 2 2 2 2 2 2 2 2 2	2 2 2 2 2 2 2
AoA CADS -ve	238	26	4 4 4 4 4 4 4 4 4 4 4 4	5 5 5 5 5 5 5
Alt coarse	190	27	6 6 6 6 6 6 6 6 6 6 6 6	8 8 8 8 8 8 8
CADS Mach coarse	195	28	6 6 6 6 6 6 6 6 6 6 6 6	8 8 8 8 8 8 8
Additional Channels for Phase 2 Flights				
NBTU alpha	029	29		
NBTU beta	030	30		
Crew module acc.	031	31	0 0 0 0 0 0 0 0 0 0 0 0	0 0 0 0 0 0 0
Accel. NBTU vert	032	32		
NBTU temperature	033	33		
Available Height and Mach Range Channels				
Height < 5k	160		7 7 7 7 7 7 7 7 7 7 7 7	8 8 8 8 8 8 8
5k < Height < 15k	162		7 7 7 7 7 7 7 7 7 7 7 7	8 8 8 8 8 8 8
15k < Height < 25k	162		7 7 7 7 7 7 7 7 7 7 7 7	8 8 8 8 8 8 8
25k < Height < 35k	163		7 7 7 7 7 7 7 7 7 7 7 7	8 8 8 8 8 8 8
35k < Height < 45k	164		6 6 6 6 6 6 6 6 6 6 6 6	7 7 7 7 7 7 7
45k < Height < 55k	164		6 6 6 6 6 6 6 6 6 6 6 6	7 7 7 7 7 7 7
Mach < 0.7	201		6 6 6 6 6 6 6 6 6 6 6 6	7 7 7 7 7 7 7
0.69< Mach < 1.8	202		7 7 7 7 7 7 7 7 7 7 7 7	8 8 8 8 8 8 8

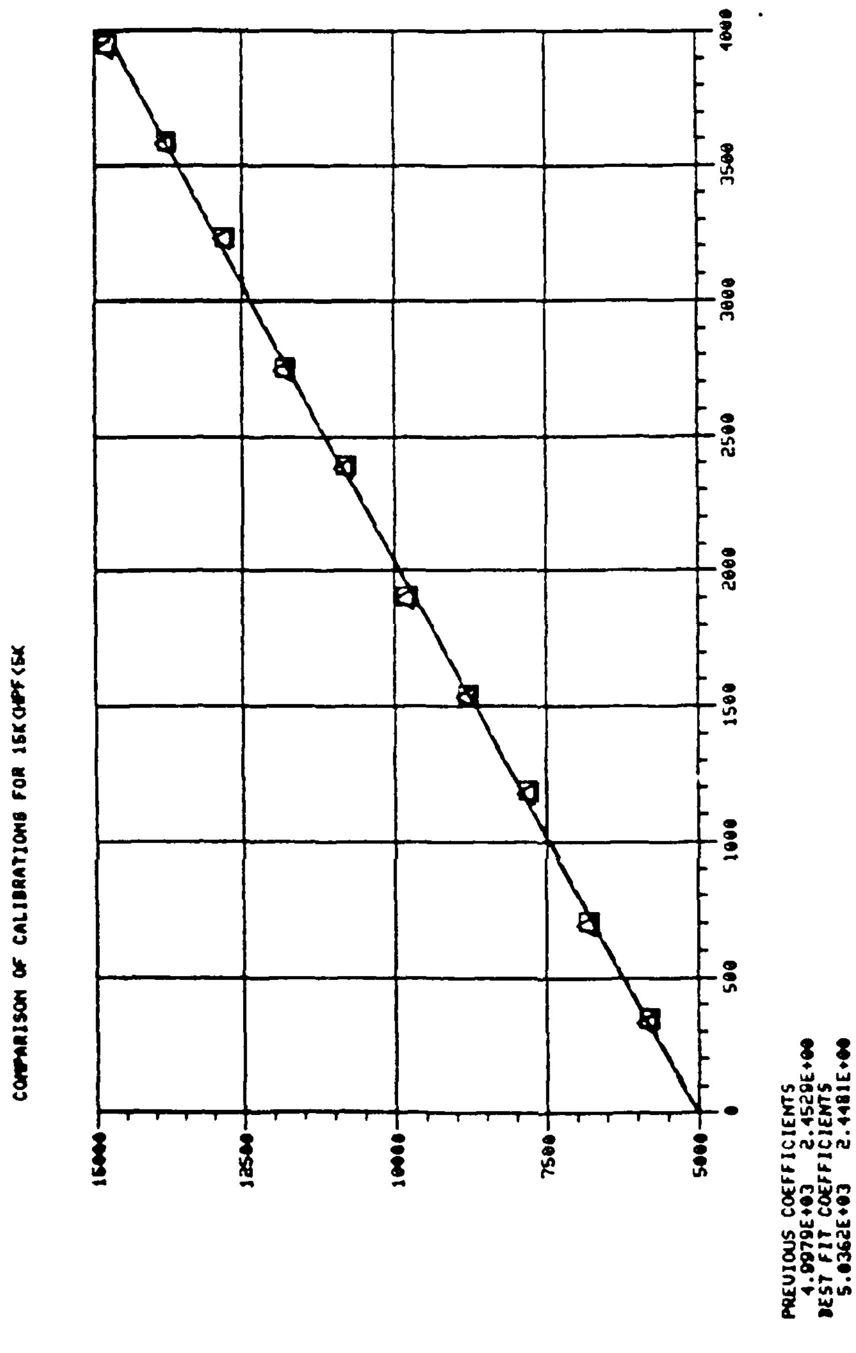


Figure A1: Example of Instrumentation Calibration

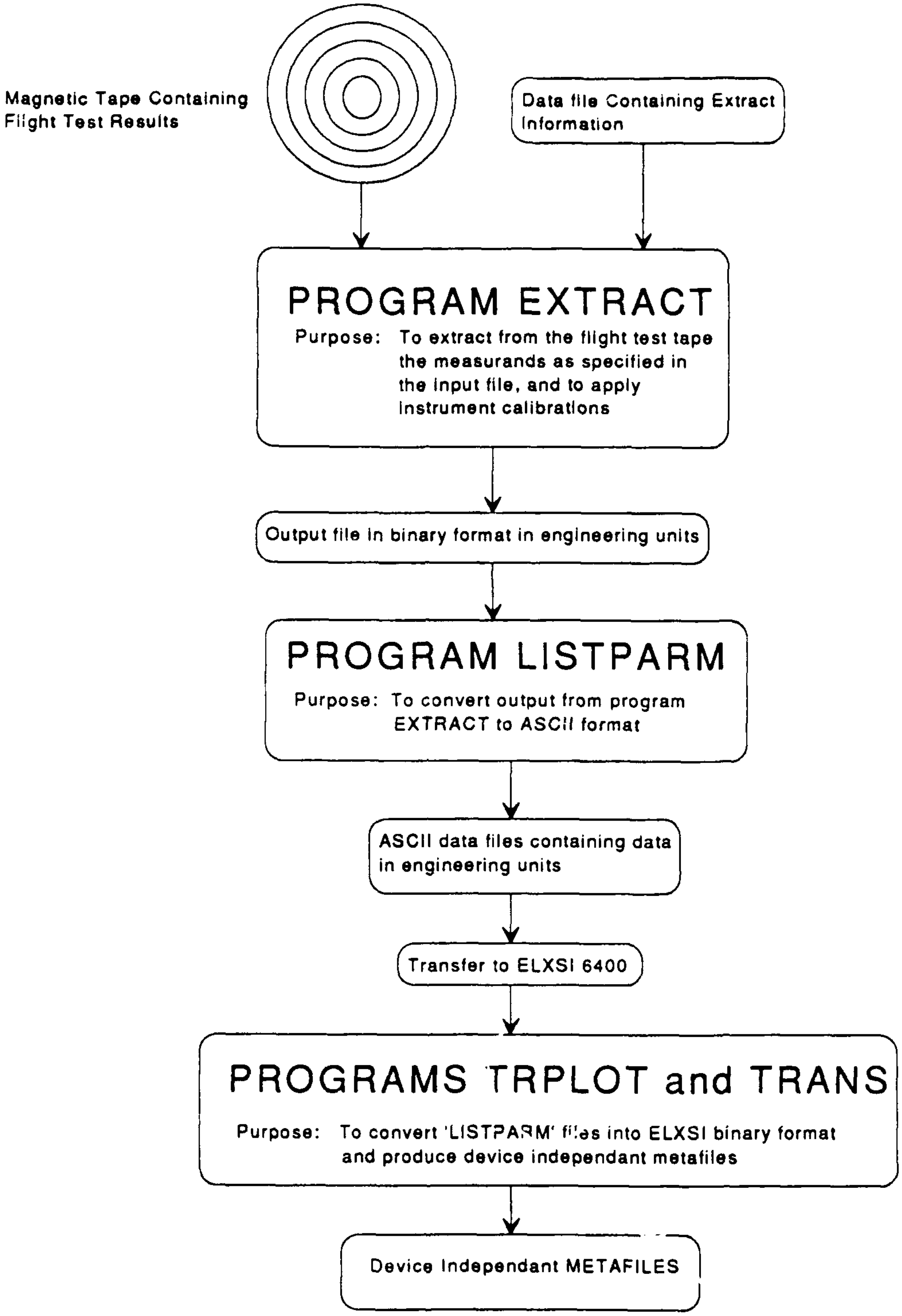


Figure A2: **Extracting Flight test data**

Appendix B Mass Characteristics Program CGCALCP1OR3

Computer program CGCALC_P1OR3 is written in the computer language FORTRAN 77 and uses manufacturers and experimental data to calculate the aircraft's mass characteristics. Figure B1 gives an outline of the program. At run time the user has a number of options available including:

- Phase 1 or phase 2 flight
- CADS or NBTU α and β measurement to be used for analysis. This information is required to allow calculation of the distance between the location of the transducers and the C of G.
- Source of normal accelerometer measurement.
- A normal accelerometer signal was available from 3 sources, C of G, crew module or from the nose boom in phase 2 flights and like the α and β signals, its position relative to the C of G has to be calculated.
- Slat retracted or extended
- Flap extension. Note that if flaps are extended, the slats will also be extended.
- Method of fuel contents calculation: Either total fuel contents along with the *automatic fuel schedule*, or the indicated fuel contents of the forward and aft tanks corrected with fuel calibration data, to calculate actual fuel tank contents. Table B1 shows the automatic fuel schedule followed if this option is used.

A typical run of program CGCALC_P1OR3 is shown below and user inputs are indicated as >

```
> CGCALC_P1OR3
  WING SWEEP ANGLE IS
> 16
  PHASE 1 OR 2 FLIGHT [1 OR 2]
> 2
  SPECIFY IF CADS OR NBTU *ALPHA* MEASUREMENT TO BE USED
  [RESPONSE IS EITHER CADS OR NBTU]
> NBTU
  SPECIFY IF CADS OR NBTU *BETA* MEASUREMENT TO BE USED
  [RESPONSE IS EITHER CADS OR NBTU]
> NBTU
  SPECIFY WHERE THE NORMAL ACCELEROMETER IS LOCATED AT
  THE CofG , ON THE NBTU OR IN THE CREW MODULE
  [RESPONSE IS CG , NBTU OR CREW]
```

```
> CREW
  ARE SLATS EXTENDED [RESPNSE IS YES or NO]
> YES
  FLAP DEFLECTION
> 25.0
  DO YOU WANT TO SPECIFY INDICATED FUEL TANK CONTENTS
  FOR AIRCRAFT A8-132 [Y OR N]
> Y
  FORWARD FUEL TANK READING IS [LBS]
> 14300
  AFT FUEL TANK READING IS [LBS]
> 6000
```

AIRCRAFT CONFIGURATION WITH INDICATED FUEL

	WEIGHT	DELTA X	DELTA Y	DELTA Z
BASIC AIRCRAFT	40073.5	529.1	.0	180.2
SWEPT WING	7174.4	523.7	40.0	176.2
PILOT	215.0	249.7	-13.0	184.2
NAVIGATOR	215.0	249.7	13.0	184.2
OIL (UNUSEABLE)	99.0	685.9	.0	154.6
OIL (USEABLE)	12.0	685.9	.0	158.3
WATER (AIR CON)	41.7	470.0	.0	155.0
PYROTECHNICS	24.8	801.1	.0	192.0
OXYGEN CONVERTER	25.0	162.8	.0	157.0
CONVERTER	17.0	162.8	.0	157.0
CREW MODUALE BALLAST	27.0	258.0	.0	170.0
WINDSHEILD WASH FLUID	8.1	254.0	.0	143.0
EMG OXY AND COMP AIR	6.8	282.9	.0	207.6
MISSION DATA PROV.	3.9	257.9	.0	179.0
CHAFF	37.0	801.1	.0	192.0
GUN (EMPTY)	1061.8	385.6	.0	152.0
FORWARD TANKS	14449.3	400.6	.0	191.5
AFT TANKS	5933.6	634.8	.0	179.9
WING TANKS TOTAL	.0	516.9	.0	194.8
WEAPON BAY TANK	.0	392.0	.0	145.4
FUEL IN LINE	184.0	515.5	.0	184.0
UNUSEABLE FUEL	292.0	494.5	.0	179.3
SPARE1	.0	.0	.0	.0
SPARE2	.0	.0	.0	.0
SPARE3	.0	.0	.0	.0

FWD TANKS CONTAIN 8515.72363 POUNDS OF FUEL MORE THAN AFT

```
FORWARD FUEL GAUGE READING= 14300.0  POUNDS
ACTUAL FORWARD FUEL        = 14449.291  POUNDS
AFT FUEL GAUGE READING     = 6000.0  POUNDS
ACTUAL AFT FUEL            = 5933.56738  POUNDS

FUEL USED                  = 14199.1406  POUNDS
HORZ. POSITION OF CG       = 24.4684524  PERCENT OF MAC
HORZ. POSITION OF CG       = 507.008697  FUSESTAX
VERTICAL POSITION OF CG    = 3.83693528  PERCENT OF MAC
VERTICAL POSITION OF CG    = 181.551803  WATERLNZ
TOTAL USEABLE FUEL WEIGHT  =20382.8593  POUNDS
TOTAL WEIGHT OF AIRCRAFT   =69900.8593 POUNDS

FLAP DEFLECTION            =25.0

******* INERTIA DATA ******

 IXX      = 73343.6718  SLUGS FT-SQ
 IYY      = 344865.781  SLUGS FT-SQ
 IZZ      = 411017.062  SLUGS FT-SQ
 IXZ      = 3976.7871  SLUGS FT-SQ
-IXZ/IXX  = -5.42212724E-02
-IXZ/IZZ  = -9.67547949E-03

********** INSTRUMENT OFFSET DATA **********

XALF =  45.5107   YALF =    .0000   ZALF =   2.5535
XB   =  44.7032   YB   =    .0000   ZB   =   3.0518
XAX  =   2.5241   YAX  =  -2.4308   ZAX  =   1.3877
XAY  =   2.4216   YAY  =  -2.4583   ZAY  =   1.3877
XAN  =  20.6674   YAN  =    .0000   ZAN  =   1.6610
```

Table B1: **Automatic Fuel Schedule**

TANK	Fuel Used In Segment (lbs)	Total fuel used (lbs)	Fuel to Burn (lbs)
Full Fuel Load Primary Weapon Bay Fuel Tank	0 1852	0 1852	34582 32730
Wing tanks	5060	2760	27670
Forward 1 tank	712	7624	26958
Forward 1 tank & Aft 2 tank until Aft 2 tank empty	4868	12492	22090
Forward 1 tank & Aft 1 tank until Forward 1 tank empty	9142	21634	12948
Forward 2 tank & Aft 1 tank until Aft 1 tank empty	4564	26198	8384
Forward 2 tank until empty	5743	31941	
Reserve	2457	34398	184
Fuel in Lines	184	34582	0

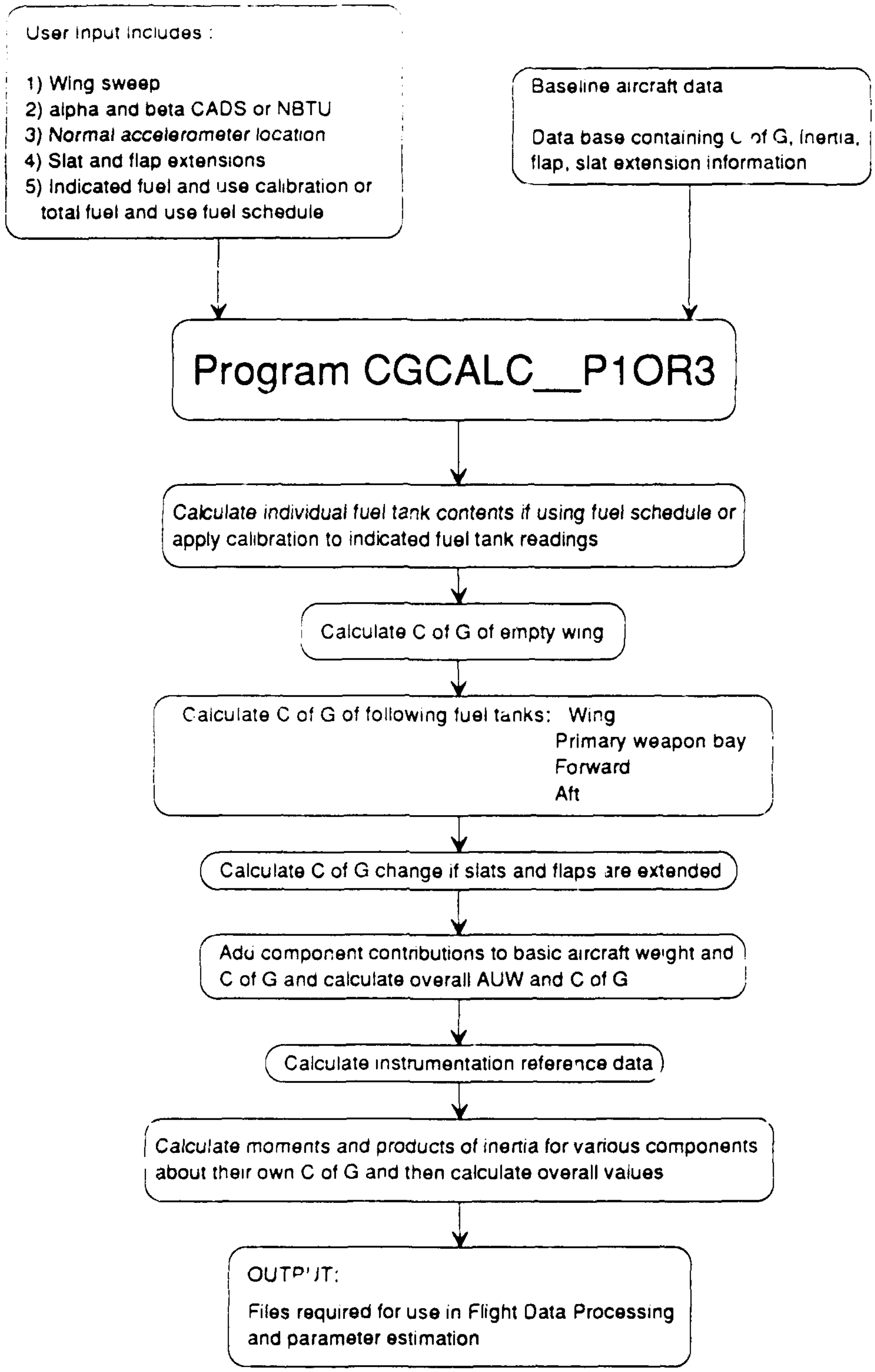


Figure B1: **Mass Characteristics Calculation**

Appendix C - Flight Data Processing Program FDP

The flight data processing program FDP reads in flight data obtained from the AFTRAS program LISTPARM and processes it into files formatted for use in a variety of analysis software programs. Using the manoeuvre given in Appendix B, an example of running FDP is shown below. A flow diagram showing the program steps is given in Figure C1. (note that all user responses are prefixed by a >):

```
> FD

**** WELCOME TC F111C FLIGHT DATA PROCESSING PROGRAM - FDP ****

*******  RUNNING PROGRAM  FDP TO PROCESS FLIGHT DATA  *********

 Enter listparm input file name in full

> P2F1E72.DAT
```

Using the instrument position information contained in the file MMLE3.PARA, which is an output from program CGCALC_P1OR3, the instrument options are displayed and can be used to check that all required options are correct. If the case to be processed is from a phase 2 flight, the phase 2 pressure error correction will be applied. Also printed out are the start and finishing times of the extracted data and the data channels and their respective calibrations. A check should be made at this stage to ensure that the required channels have been extracted.

```
 NBTU Alpha instrument is being used
 NBTU Beta instrument is being used
 Crew module Normal Accel instrument is being used
 Phase 2 PE Corrections Applied

      INFORMATION ABOUT DATASET
      ----------- ----- -------
       NO. OF         INC.        START TIME       END TIME
     MEASURANDS

           33    1.66699998E-02      1040.0             1109.0

 DATASET DESCRIPTION
  TRIAL ID   TRIAL PHASE     A/C ID        FLIGHT NO.
   TS    1691       02          A08B-132           001

             NO.  SHORT        SHORT      MEASURAND
```

	TITLE	UNITS	DESCRIPTION
1	ACCEL VERT	"G"	BI-170- 4
2	ACCEL LAT	"G"	BI-171- 4
3	ACC LNG CG	"G"	BI-172- 5
4	PITCH RATE	DEG/SEC	BI-173- 2
5	ROLL RATE	DEG/SEC	BI-174- 3
6	YAW RTE CG	DEG/SEC	BI-175- 3
7	HPF < 5K	FEET	BI-160- 8
8	MACH <.7	MACH	BI-201- 7
9	CAS FINE T	KCAS	BI-184- 8
10	NBTU ALPHA	DEGREES	BI- 23- 1
11	NBTU BETA	DEGREES	BI- 25- 2
12	STAB RH	DEGREES	BI- 40- 4
13	PTCHACC CG	RAD/SEC	BI-176- 1
14	ROLLACC CG	RAD/SEC	BI-177- 1
15	ADI PITCH	DEGREES	BI-214- 4
16	ADI BANK	DEGREES	BI-215- 4
17	STAB LH	DEGREES	BI- 39- 4
18	RUD POSN	DEGREES	BI- 41- 1
19	RPEDAL POS	INCHES	BI- 55- 1
20	SPL LH O/B	DEGREES	BI- 43- 2
21	SPL RH O/B	DEGREES	BI- 44- 3
22	WNGSWPXDCR	DEGREES	BI- 45- 2
23	YWANG ACC	RAD/SEC	BI-178- 1
24	STK POS LG	INCHES	BI- 53- 2
25	STK POS LT	INCHES	BI- 54- 2
26	AOACADS-VE	DEGREES	BI-238- 5
27	ALT CRSCAD	FEET	BI-190- 8
28	CADS M CSE	MACH	BI-195- 8
29	AOACADS+VE	DEGREES	BI-237- 5
30	BETA CADS	DEGREES	BI-188- 4
31	CM ACC VRT	"G"	BI-166- 1
32	ACC-X NBTU	"G"	BI- 28- 1
33	NBTU A TMP	DEGREES C	BI- 31- 1

The option is available at this stage to select different portions of the extracted time histories for analysis.

```
Do you wish to delete data from start of time history ?

> Y
Enter Aftras tape time to begin time history
```

```
> 1069

 Do you wish to delete data from end of time history ?

> Y

 Enter Aftras tape time for data cut-off

> 1080
```

Type of phase lags to be used

```
 Do you want standard Channel lags ?
 For standard Phase 1 lags type ............[P1]
 For standard Phase 2 lags type ............[P3]
 For standard Phase 2 lags with the crew
 module norm accelerometer type  ...........[CM]
 For non standard lags type ................[N]

> CM

 Standard Phase 2 Crew Module lags applied

 ** Flight Data now being processed **
```

The processing of the raw flight data now commences and several files are created for use in the analysis as shown below:

- FPR.LON and FPR.LAT. These files provide the input data for the flight path reconstruction programs ARLFPRLON2 and ARLFPRLAT which are used to calculate the flow vane calibration constants. Note: the data for these programs are required in the following units. Lengths in meters, angles in degrees, angular rates in radians per second, velocity (VTAS) in meters per second and accelerations at the centre of gravity in meters per second per second. Because the instrumentation package was not located at the centre of gravity, corrections have to be made to the measured signals to give the C of G values. Using Figure C2 and the equations given below the C of G offset corrections are made.

$$a_{x_{cg}} = a_{x_m} - \frac{\Delta z \dot{q}}{g} + \frac{\Delta y \dot{r}}{g} + \frac{\Delta x q^2}{g} + \frac{\Delta x r^2}{g}$$

$$a_{y_{cg}} = a_{y_m} - \frac{\Delta x\dot{r}}{g} + \frac{\Delta z\dot{p}}{g} + \frac{\Delta y r^2}{g} + \frac{\Delta y p^2}{g}$$

$$a_{z_{cg}} = a_{z_m} - \frac{\Delta x\dot{q}}{g} + \frac{\Delta y\dot{p}}{g} - \frac{\Delta z q^2}{g} - \frac{\Delta z p^2}{g}$$

- MMLE3.DAT. This is the raw data file required for use in the parameter identification program MMLE3. The data for this program are required in the following units:

  angles in degrees, angular rates in radians per second velocity (VTAS) and accelerations in 'g' measured at that instrumentation pack.

- F-111C.dat. This file can be used to provide control input time histories into a six degree of freedom model of the F111-C enabling comparisons to be made between the calculated response of the aircraft during the flight test manoeuvre and the actual measured response.

```
Have a glorious day in Melbourne !

************ FLIGHT DATA PROCESSING COMPLETE ****************
```

The flight data processing has been completed and analysis can commence.

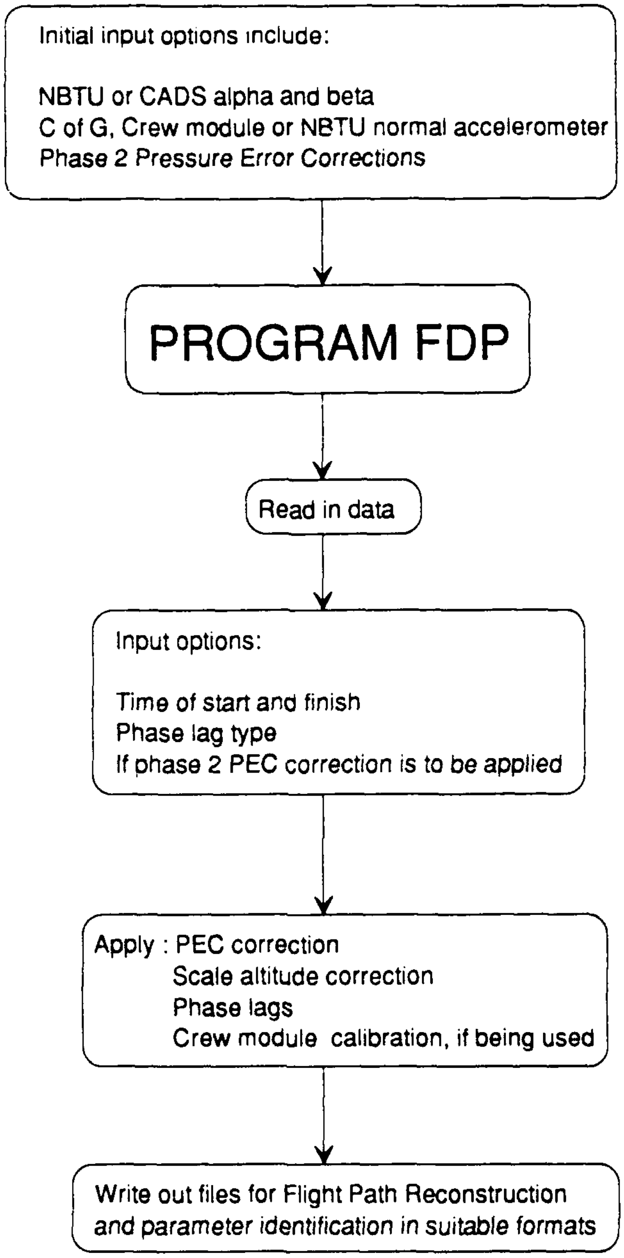


Figure C1: **Flight Data Processing**

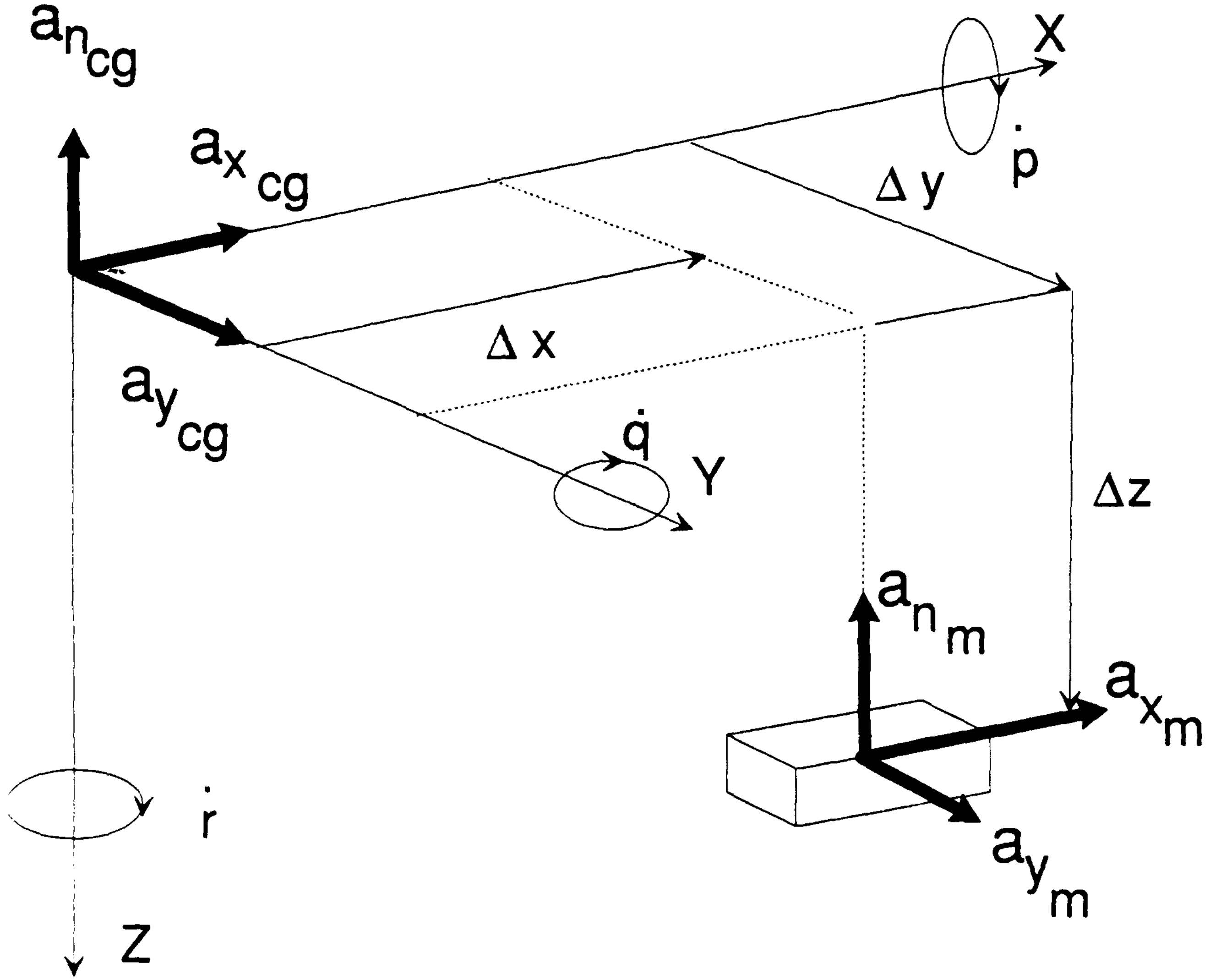


Figure C2: **Notation for Linear and Angular Accelerometers**

Appendix D - Pressure Error Correction

For the manoeuvres flown with the NBTU fitted a correction is required to the data calculated by the Central Air Data System due to the change in the static pressure source. This correction has to include the differences between the static pressures at the two locations and also the in-built corrections which are used by the CADS system for data from the aircraft system. A calibrated Mirage chase aircraft was used to establish the magnitude of the error of the static pressure source for aircraft A8-132 with the NBTU fitted. The static and impact pressures can be calculated from the following equations taken from Reference [19]. The static air pressure p_{sp} for the pacer Mirage aircraft at a level h_{pacer} is given by:

$$p_{sp} = p_0\left(\frac{T_0 - Lh_{pacer}}{T_0}\right)^{\frac{g}{LR}}$$

The ambient pressure p_a can be then calculated using the known pressure error correction from the pacer aircraft.

For the F-111C aircraft with an indicated altitude of h_i the static pressure p_s is calculated from:

$$p_s = p_0\left(\frac{T_0 - Lh_i}{T_0}\right)^{\frac{g}{LR}}$$

The differential pressure Δp is

$$\Delta p = p_s - p_a$$

From the F-111C's indicated airspeed, VIAS the indicated impact pressure q_{ci} is calculated

$$q_{ci} = p_0\left[\left[1 + \frac{(\gamma-1)}{2}\left(\frac{VIAS}{a_0}\right)^2\right]^{\frac{\gamma}{\gamma-1}} - 1\right]$$

The chase and F-111C aircraft were flown in close formation at various values of VIAS and the indicated altitude from the two aircraft was recorded.

This data was analysed by ARDU using the known pressure correction of the chase aircraft to give the static pressure corrections shown in Table D1. Measurements were not made at supersonic speeds. Data from the subsonic tests were extrapolated to supersonic speeds using information from tests on similar installations.

The corrections to velocity and altitude are calculated using the values of $\Delta P/qci$ given in Table D1 by the following method:

For the given indicated pressure height h_i calculate the static pressure p_s using the following equations:

For $H_i \leq 36089.0$ feet

$$p_s = p_0\left(\frac{T_0 - Lh_i}{T_0}\right)^{\frac{g}{LR}}$$

For $H_i > 36089.0$ feet

$$p_s = p_1 e^{\frac{-g}{RT_1}(h-h_1)}$$

where T_1 and p_1 are the temperature and static pressure at 36089 feet

Given the indicated airspeed VIAS, the indicated impact pressure is calculated using the following equation :

$$q_{ci} = p_0 \left[\left[1 + \frac{(\gamma - 1)}{2} \left(\frac{VIAS}{a_0} \right)^2 \right]^{\frac{\gamma}{\gamma-1}} - 1 \right]$$

Using q_{ci} and p_s calculated above, the indicated Mach number M_i is calculated:

$$M_i = \left[\frac{2}{\gamma - 1} \left(\frac{q_i}{p_s} + 1 \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]^{0.5}$$

From Table D1 for any given value of M_i interpolate for a value of $\Delta p/q_{ci}$ from which:

$$\Delta p = \Delta p/q_{ci} \times q_{ci}$$

can be calculated. The actual impact pressure is calculated to be :

$$q_c = q_{ci} + \Delta p$$

Using this calibrated impact pressure calculate the calibrated airspeed VCAS

$$VCAS = a_0 \left[\left(\frac{2}{\gamma - 1} \right) \left(\left(\frac{q_c}{p_0} + 1 \right)^{\frac{\gamma-1}{\gamma}} - 1 \right) \right]^{0.5}$$

The ambient calibrated pressure is :

$$p_a = p_s - \Delta p$$

And the calibrated pressure altitude is :

For $H_i \leq 36089.0$ feet

$$h_{pc} = \frac{T_0 - T_0 \left(\frac{p_a}{p_0} \right)^{\frac{LR}{g}}}{L}$$

For $H_i > 36089.0$ feet

$$h_{pc} = \frac{RT_1}{g} log_e \left(\frac{p_a}{p_1} \right) + 36089$$

Where T_1 and p_1 are the temperature and static pressure at 36089 feet

Table D1: **Pressure Error Correction Data**

Mach No.	Alt	V_i	q_{ci}	ΔP	$\Delta P/q_{ci}$
0.50	1000	325	379.71	16.127	0.0425
0.60	1000	390	561.26	28.956	0.0516
0.70	1000	456	791.64	45.215	0.0571
0.80	1000	520	1066.0	68.611	0.0644
0.90	1000	588	1420.0	112.000	0.0787
0.95	1000	620	1613.0	145.000	0.0902

Appendix E - Scale Altitude Correction

Scale altitude error is the term used to describe the difference between calibrated airspeed VCAS, which is the indicated airspeed VIAS corrected for any pressure errors, and instrumentation errors, and the equivalent airspeed VEAS. The difference between VCAS and VEAS occurs because airspeed measuring instrument calibrations are simplified by assuming a constant value of unity for the pressure ratio $\delta = p/p_0$ in part of the calibration equation. This error can be neglected at low speeds and low altitudes but is significant at high Mach numbers and high altitudes. Bernoulli's equation for the total pressure in compressible flow can be expressed as a function of Mach number in the absence of any shock wave as:

$$p_t = p\left[1 + \frac{(\gamma - 1)}{2} M^2\right]^{\frac{\gamma}{\gamma-1}} ...(E1)$$

which is the pitot pressure p_p sensed by a pitot tube in subsonic flow. For supersonic flow, the pitot pressure is modified by the presence of a normal shock at the mouth of the pitot tube. The ratio of total pressure across a shock is given by :

$$\frac{p_{t_2}}{p_{t_1}} = \left[1 + \frac{2\gamma}{(\gamma + 1)}(M^2 - 1)\right]^{\frac{1}{1-\gamma}} ...(E2)$$

Therefore for $M \leq 1.0$, $p_p = p_t$

$$\frac{p_p}{p} = \left[1 + \frac{(\gamma - 1)}{2} M^2\right]^{\frac{\gamma}{\gamma-1}} ...(E3)$$

and for $M \geq 1.0$, $p_p \neq p_t$

$$\frac{p_p}{p} = \frac{p_{t_2}}{p_{t_1}} \times \frac{p_{t_1}}{p} = \left[1 + \frac{2\gamma}{(\gamma + 1)}(M^2 - 1)\right]^{\frac{1}{1-\gamma}} \left[\frac{(\gamma + 1)}{2} M^2\right]^{\frac{\gamma}{\gamma-1}} ...(E4)$$

The impact pressure, which is the difference between pitot and stagnation pressure is given by the relationship :

$$q_c = p_p - p ...(E5)$$

Calibrated airspeed VCAS is obtained from the indicated airspeed, corrected for any pressure measurement errors that have been introduced by the air data system and for any mechanical errors in the instrument. VCAS is the airspeed that would be required at sea-level in a standard atmosphere to give the same impact pressure as that sensed at the particular height and true airspeed considered. For a sea level ISA atmosphere:

When $VCAS/a_0 \leq 1.0$

$$\frac{q_c}{p_0} = \frac{p_p - p}{p_0} = \left[1 + \frac{(\gamma - 1)}{2}\left(\frac{VCAS}{a_0}\right)^2\right]^{\frac{\gamma}{\gamma-1}} - 1 ...(E6)$$

When $VCAS/a_0 > 1.0$

$$\frac{q_c}{p_0} = \frac{p_p - p}{p_0} = \left[1 + \frac{2\gamma}{(\gamma+1)}\left(\left(\frac{VCAS}{a_0}\right)^2 - 1\right)\right]^{\frac{1}{1-\gamma}} \left[\frac{(\gamma+1)}{2}\left(\frac{VCAS}{a_0}\right)^2\right]^{\frac{\gamma}{\gamma-1}} - 1 ...(E7)$$

To find the relationship between calibrated airspeed and Mach number we can equate the above expressions using the substitution

$$\delta = \frac{p}{p_0}$$

Note: Three cases have to be considered: For $VCAS/a_0 \leq 1.0$ and $M \leq 1.0$ equating E6 and E3

$$\left[\left[1 + \frac{(\gamma-1)}{2}\left(\frac{VCAS}{a_0}\right)^2\right]^{\frac{\gamma}{\gamma-1}} - 1\right] = \delta\left[\left[1 + \frac{(\gamma-1)}{2}M^2\right]^{\frac{\gamma}{\gamma-1}} - 1\right]$$

For $VCAS/a_0 \leq 1.0$ and $M > 1.0$ equating E6 and E4

$$\left[\left[1 + \frac{(\gamma-1)}{2}\left(\frac{VCAS}{a_0}\right)^2\right]^{\frac{\gamma}{\gamma-1}} - 1\right] = \delta\left[\left[1 + \frac{2\gamma}{(\gamma+1)}(M^2 - 1)\right]^{\frac{1}{(1-\gamma)}} \left[\frac{(\gamma+1)}{2}M^2\right]^{\frac{\gamma}{\gamma-1}} - 1\right]$$

For $VCAS/a_0 > 1.0$ and $M > 1.0$ equating E7 and E4

$$\left[1 + \frac{2\gamma}{(\gamma+1)}\left(\left(\frac{VCAS}{a_0}\right)^2 - 1\right)\right]^{\frac{1}{1-\gamma}} \left[\frac{(\gamma+1)}{2}\left(\frac{VCAS}{a_0}\right)^2\right]^{\frac{\gamma}{(\gamma-1)}} - 1 =$$

$$\delta\left[\left[1 + \frac{2\gamma}{(\gamma+1)}(M^2 - 1)\right]^{\frac{1}{1-\gamma}} \left[\frac{(\gamma+1)}{2}M^2\right]^{\frac{\gamma}{\gamma-1}} - 1\right]$$

Because δ is a function of pressure height, ie p is the ambient pressure at a given height, the above equations show that there is a relationship between VCAS, M and pressure height. Given

$$VEAS = VTAS(\frac{\rho}{\rho_0})^{\frac{1}{2}}$$

and

$$a = \frac{\gamma p}{\rho}$$

$$a_0 = \frac{\gamma p_0}{\rho}$$

then

$$VEAS = Ma\left(\frac{\rho}{\rho_0}\right)^{\frac{1}{2}}$$

$$= M\left(\frac{\gamma p}{\rho}\right)^{\frac{1}{2}}\left(\frac{\rho}{\rho_0}\right)^{\frac{1}{2}}$$

$$= M\left(\frac{\gamma p}{\rho_0}\right)^{\frac{1}{2}}$$

$$= M a_0 \delta^{\frac{1}{2}}$$

Substituting for $VEAS = a_0 M \delta^{\frac{1}{2}}$ and $\gamma = 1.4$ the relationships between VCAS, VEAS and pressure height can be developed for the three cases.

For $VCAS/a_0 \leq 1.0$ and $VEAS/(a_0\gamma)^{0.5} \leq 1.0$ then

$$\left[\left(1+0.2\left(\frac{VCAS}{a_0}\right)^2\right)^{3.5}-1\right] = \delta\left[\left(1+\frac{0.2}{\delta}\left(\frac{VCAS}{a_0}\right)^2\right)^{3.5}-1\right]$$

For $VCAS/a_0 \leq 1.0 < VCAS/(a_0\gamma)^{0.5}$ then

$$\left[\left(1+0.2\left(\frac{VCAS}{a_0}\right)^2\right)^{3.5}-1\right] = \delta\left[\frac{\frac{1.2^6\times 5^{2.5}}{\delta}\left(\frac{VEAS}{a_0}\right)^2}{\left(7-\delta\left(\frac{a_0}{VEAS}\right)^2\right)^{2.5}}-1\right]$$

For $VCAS/a_0 > 1.0$ and $VCAS/(a_0\gamma)^{0.5} > 1.0$ then

$$\left[\frac{1.2^6\times 5^{2.5}\left(\frac{VCAS}{a_0}\right)^2}{\left(7-\left(\frac{a_0}{VCAS}\right)^2\right)^{2.5}}-1\right] = \delta\left[\frac{\frac{1.2^6\times 5^{2.5}}{\delta}\left(\frac{VEAS}{a_0}\right)^2}{\left(7-\delta\left(\frac{a_0}{VEAS}\right)^2\right)^{2.5}}-1\right]$$

From the above expressions the difference between calibrated airspeed VCAS and the equivalent air speed VEAS can be calculated. At sea level $\delta = 1$ so the values of VCAS and VEAS are identical. At higher altitudes where $\delta \neq 1.0$ the difference between the two increases. This difference has been called scale altitude error. Figure E1 shows the value of scale altitude error as a function of pressure height and Mach number. For airspeed measurement purposes it is necessary to make an adjusment to VCAS especially at high altitudes and Mach numbers.

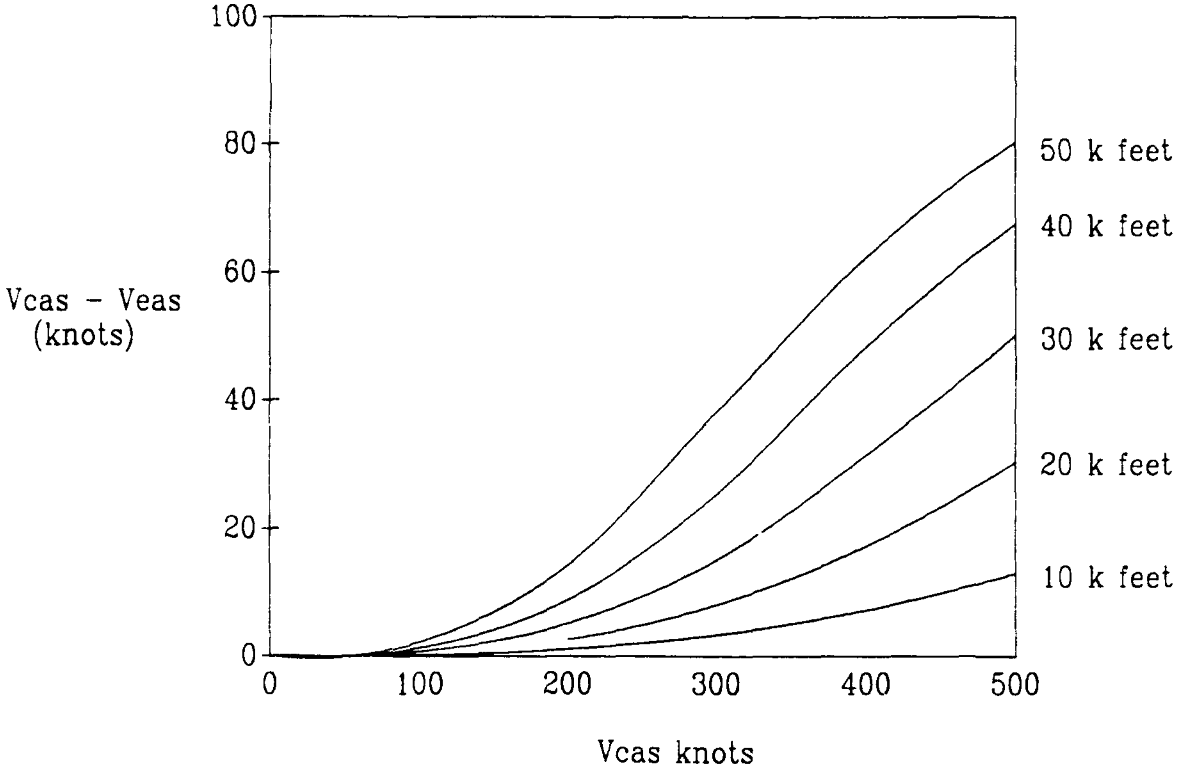


Figure E1: Scale Altitude Correction to VCAS

Appendix F - Flight Path Reconstruction Programs

The programs used are described in detail in References [12] and [13] and in this section an example will be used to illustrate how they are run on the ELXSI computer. The first step is to set up the data input table 'DATIN.DAT' and this is done using program FPRSORT. As with previous examples user input is prefixed by a > symbol.

```
> fprsort
  NAME OF INPUT FILE
> datin.long

  LONGITUDINAL CASE
  TABLE 1 : STATE VARIABLES

     1     U        YES          2     V        NO
     3     W        YES          4     PHI      NO
     5     THE      YES          6     PSI      NO
     7     H        YES          8     BAX      YES
     9     BAY      NO          10     BAZ      YES
    11     BP       NO          12     BQ       YES
    13     BR       NO          14     LAX      NO
    15     LAY      NO          16     LAZ      NO
    17     LP       NO          18     LQ       NO
    19     LR       NO          20     BVEL     YES
    21     BBET     NO          22     BALP     YES
    23     BPHI     NO          24     BTHE     YES
    25     BPSI     NO          26     BH       YES
    27     LVEL     NO          28     LBET     NO
    29     LALP     YES         30     LPHI     NO
    31     LTHE     NO          32     LPSI     NO
    33     LH       NO          34
 TABLE 2 : INPUTS

     1     Ax       YES          2     Ay       NO
     3     Az       YES          4     P        NO
     5     Q        YES          6     R        NO
 TABLE 3 : OUTPUTS

     1     V        YES          2     BET      NO
     3     ALP      YES          4     PHI      NO
     5     THE      YES          6     PSI      NO
     7     H        YES          8
```

```
TABLE # TO BE EDITED?
(0 WILL TERMINATE CHANGES,-1     WILL GIVE TABLE CONTENTS):
```

The state variables, inputs and outputs to be used for analysis are displayed and can be changed. For this case (a longitudinal pitch up manoeuvre), the option for changing the states variable inputs and outputs are not exercised.

```
> 0
```

The start and finishing times are displayed along with the position (in meters) of the angle of attack α and angle of sideslip β measurement devices. In the listing below the finishing time TEND is changed to 6.49 seconds and the distance to the α measuring device XALP is increased to 13.862 meters.

```
    1     TO           .00000E+00
    2     TEND         .40000E+02
    3     DT           .60000E+02
    4     XALP         .45000E+01
    5     YALP         .00000E+00
    6     XBET         .00000E+00
    7     ZBET         .00000E+00
 NO. AND VALUE TO CHANGE (EG. 3 .01) OR 0 0 TO TERMINATE
2 6.49
    1     TO           .00000E+00
    2     TEND         .64000E+01
    3     DT           .60000E+02
    4     XALP         .45000E+01
    5     YALP         .00000E+00
    6     XBET         .00000E+00
    7     ZBET         .00000E+00
 NO. AND VALUE TO CHANGE (EG. 3 .01) OR 0 0 TO TERMINATE
4 13.862
    1     TO           .00000E+00
    2     TEND         .64000E+01
    3     DT           .60000E+02
    4     XALP         .13862E+01
    5     YALP         .00000E+00
    6     XBET         .00000E+00
    7     ZBET         .00000E+00
```

```
 NO. AND VALUE TO CHANGE (EG. 3 .01) OR 0 0 TO TERMINATE
0 0
    1     NPAS No of passes through data                                    5
    2     ITER No of local iterations                                       0
    3     NDEX No of samples before averaging                             154
    4     IFIL filtering of inputs write to FILINP.DAT                      1
    5     ICYL samples between writes to the output files                   1
    6     IRES residuals & S.D. written to RES.DAT & SDEV.DAT               1
    7     IBIAS inst. param. written to PARAM.DAT on last pass              1
 NO. AND VALUE TO CHANGE (EG. 3 3800) OR 0 0 TO TERMINATE
 THE LAST FOUR PARAMETERS ARE TRUE OR FALSE SWITCHES
 0 - FALSE     1 - TRUE
0 0
```

For longitudinal manoeuvres the program ARLFPR2LON is used and for lateral cases program ARLFPRLAT is used. For the program to commence running type:

```
> arlfpr2lon
```

Shown below is part of the files DATOUT.DAT which summarises the results obtained:

```
 *****************************************************************************
    FLIGHT PATH RECONSTRUCTION: PROGRAM ARLFPR  RUN   1
 *****************************************************************************

 ** PARAMETERS OF THE FILTERING PROCEDURE **

 START TIME =     .00000E+00 SECS  **  FINAL TIME =     .64000E+01 SECS

 DATA SAMPLING PERIOD =     .16667E-01 SECS

POSITION OF THE SIDESLIP AND INCIDENCE ANGLE SENSORS

  XBETA =     .00000E+00   ZBETA =     .00000E+00
 XALPHA =     .13862E+02  YALPHA =     .00000E+00
```

** INITIAL STATE ESTIMATE **

VARIABLE	ESTIMATE	VARIANCE
U	.12394E+03	.40000E+01
W	.14342E+02	.40000E+01
THET	.11188E+00	.40000E-03
H	.39265E+03	.40000E+01

** INITIAL ESTIMATE OF PARAMETERS **

VARIABLE	ESTIMATE	VARIANCE	NOISE VARIANCE
BAX	.00000E+00	.50000E-01	.00000E+00
BAZ	.00000E+00	.50000E-01	.00000E+00
BP	.00000E+00	.50000E-03	.00000E+00
BVEL	.00000E+00	.10000E+01	.00000E+00
BALP	.00000E+00	.50000E-03	.00000E+00
BTHE	.00000E+00	.50000E-03	.00000E+00
BH	.00000E+00	.10000E+01	.00000E+00
LALP	.00000E+00	.50000E-03	.00000E+00

** DATA PROCESSING NO. 5 **

** PARAMETERS ESTIMATE **

VARIABLE	FINAL PREDICTION BY THE EKF	
	ESTIMATE	STANDARD ERROR
BAX	-.14450E+01	.21644E-01
BAZ	-.87557E-01	.41061E-02
BP	-.84207E-03	.29815E-04
BVEL	-.13971E+02	.21119E+00
BALP	.93545E-01	.87074E-03
BTHE	.74014E-01	.94759E-03
BH	.27258E+01	.41214E+00
LALP	-.20941E-01	.99603E-03

Appendix G - A priori Data from Six Degree of Freedom Flight Dynamic Model

The six degree of freedom flight dynamic mathematical model of the F-111C is used to obtain *a priori* values of the aerodynamic stability and control derivatives for use in the parameter estimation techniques. This program stores the aerodynamic data in data tables in both derivative and coefficent form. The coefficent form is employed where the aerodynamic forces are non-linear. Additional subroutines were developed to extract local derivatives from the non-linear model using the ACSL simulation language Jacobian analysis facility. Details of this procedure are given in References [21] and [22]. Configuration data and initial conditions for the simulation are contained in file TABLEE.NEW shown below. The aircraft's mass characteristics obtained from program CGCALC_P1OR3 described in Appendix B, are presented in the first part of the table.

WEIGHTS AND INERTIAS

6 QUANTITIES

#(I)	QUANTITY	VALUE(F)	#(I)	QUANTITY	VALUE(F)
1	WEIGHT	69900.0000000	2	IYY	344865.0000000
3	IXX	73343.0000000	4	IZZ	411017.0000000
5	IXZ	976.0000000	6	BLANK	.0000000

INITIAL CONDITIONS (ALFW IS OVERWRITTEN BY TRIM ROUTINE)

18 QUANTITIES

#(I)	QUANTITY	VALUE(F)	#(I)	QUANTITY	VALUE(F)
1	GAMMAO	.0000000	2	PO	.0000000
3	ALFW	3.6007390	4	QO	.0000000
5	BETAO	.0000000	6	RO	.0000000
7	TRACKO	.0000000	8	XO	.0000000
9	PHIDO	.0000000	10	YO	.0000000
11	XMACHO	.3150000	12	ALTO	1000.0000000
13	VWN	.0000000	14	VWE	.0000000
15	VWD	.0000000	16	DGAMMA	.0000000
17	DVR	.0000000	18	CDWPS	.0000000

AIRCRAFT GEOMETRY

4 QUANTITIES

#(I)	QUANTITY	VALUE(F)	#(I)	QUANTITY	VALUE(F)
1	SWEEP	16.0000000	2	XONC	.2446800
3	ZONC	.0380852	4	BLANK	.0000000

With file TABLEE.NEW altered to suit the particular case, running of the model can commence (> indicates user response):

```
> f111latlong
```

Information describing the aerodynamic data base used in the simulation is output to the screen and the ACSL commands and flags required to be set by the user are provided. These included the commands required to set up the initial run time parameters and, for the example shown, to set the flap deflection to 25 degrees, the trim flag to true to ensure the equations are trimmed in equilibrium, and the derivative finder option to true.

```
> S CMD = 10

> S FLAPS = 25.

> S CTTRIM = .T.

> S DEFIND = .T.

> START
```

The current status of the main switches and flags defining the control system settings, the analysis facilities, and the configuration is presented below: The CONVERGENCE signal indicates that trimming of the aircraft has taken place.

```
*****************************************************
*         CURRENT STATUS OF SET UP SWITCHES         *
*****************************************************
*             CONTROLS SYSTEM SWITCHES              *
*****************************************************
* RDAMP  * ROLL DAMPER                  *    F     *
* PDAMP  * PITCH DAMPER                 *    F     *
* YDAMP  * YAW DAMPER                   *    F     *
* RCAUG  * ROLL CONTROL AUGMENTATION    *    F     *
* PCAUG  * PITCH CONTROL AUGMENTATION   *    F     *
* STA    * SERIES TRIM ACTUATOR         *    F     *
*****************************************************
```

```
*****************************************************
*              GENERAL SET UP SWITCHES              *
*****************************************************
* RADAPT * ROLL ADAPTIVE GAIN FINDER     *    F     *
* PADAPT * PITCH ADAPTIVE GAIN FINDER    *    F     *
* DEFIND * AERODYNAMIC DERIVATIVE FINDER *    T     *
* FLTDAT * FLIGHT DATA INPUT             *    F     *
* CTTRIM * TRIM AIRCRAFT WITH THRUST     *    T     *
* PTRIM  * TRIM AIRCRAFT WITH ELEVATORS  *    F     *
* RTRIM  * TRIM WITH STEADY SIDESLIP     *    F     *
* DUMP   * GENERATE DEBUG OUTPUT         *    F     *
* PLOTFL * PRODUCE 3-D GRAPICS FILE      *    F     *
*****************************************************
*                IMPORTANT CONSTANTS                *
*****************************************************
* XCG    * CENTRE OF GRAVITY POSITION    *  .24468  *
* RFB    * ROLL CONTROL FEEDBACK         * 1.00000  *
* AYFB   * LATERAL ACCELEROMETER F/BACK  * 1.00000  *
*****************************************************
*        TAKE OFF AND LANDING CONFIGURATION         *
*****************************************************
* LANDGR * LANDING GEAR DOWN             *    F     *
* SPEEDB * SPEED BRAKE DOWN              *    F     *
* SLATS  * LEADING EDGE SLATS EXTENDED   *    T     *
* GRDEFF * IN GROUND EFFECT              *    F     *
* FLAPS  * TRAILING EDGE FLAPS EXTENSION *25.00000  *
*****************************************************

CONVERGENCE

> STOP
```

File F111DERV.OUT shown below contains the *a priori* derivatives calculated by the simulation program in a format suitable for use in the input file FAR01.DAT used by program MMLE3.

```
*********NON-DIMENSIONAL LONGITUDINAL AERODYNAMIC DERIVATIVES. *********

          CTv     =     -.2937838
          CLv     =     -.0001830
          CDv     =     -.2937219
          CMv     =     -.0106612
```

CLalpha	=	.1316456
CDalpha	=	.3009140
CMalpha	=	-.0191155
CLdalpha	=	2.5420000
CMdalpha	=	-4.6251057
CLq	=	5.7770969
CMq	=	-14.2470031

*********NON-DIMENSIONAL LONGITUDINAL CONTROL DERIVATIVES. *********

CLeta	=	.0174604
CDeta	=	-.0020467
CMeta	=	-.0353430

*********NON-DIMENSIONAL LATERAL AERODYNAMIC DERIVATIVES. *********

CYbeta	=	-1.0751711
Clbeta	=	-.0471412
CNbeta	=	.0671741
CYp	=	-.0695050
Clp	=	-.4218597
CNp	=	.0151035
CYr	=	.3232533
Clr	=	.0426392
CNr	=	-.1817579
CYdbeta	=	-.1191400
Cldbeta	=	-.0109330
CNdbeta	=	.0351486

*********NON-DIMENSIONAL LATERAL CONTROL DERIVATIVES. *********

CYaileron	=	.0726516
Claileron	=	-.0345603
CNaileron	=	-.0397724
CYrudder	=	.0984668
Clrudder	=	.0097033
CNrudder	=	-.0227910
CYspoiler	=	.0046761
Clspoiler	=	-.0385813
CNspoiler	=	-.0094143

Appendix H - Parameter Identification Program MMLE3

The data processing described in previous Appendices is carried out to prepare the flight data for use by the parameter identification program MMLE3. Considerable background knowledge is needed to apply the program. Only the program operation procedures will be covered in this Appendix. A detailed description of the program MMLE3 is given in Reference [15]. Shown below is an example of an input file FAR01.DAT which provides all the data required for the third run of a phase 2 flight, event 72, along with a brief comment.

```
STANDARD AIRCRAFT ROUTINES
END ONCE
NEW
H1620035.OV3    16  TS1691 MMLE3 F111C LONG STAB P2F1E72 RUN 3 SLATS 35
FLAPS
 $WIND,
 AREA=550,CHORD=8.8,SPAN=70.0,
 CG=.24509,
 STAB=T,
 PRINT =F,
```

Angle of attack scale factor K_α and instrument locations

```
  KALF=1.06,
  XALF =  45.5107,   YALF =    .0000 , ZALF =   2.5535
  XB   =  44.7032,   YB   =    .0000 , ZB   =   3.0518
  XAX  =   2.5241,   YAX  = -2.4308 , ZAX  =   1.3877
  XAY  =   2.4216,   YAY  = -2.4583 , ZAY  =   1.3877
  XAN  =  20.6674,   YAN  =    .0000 , ZAN  =   1.6610
  $END
0.
0.
0.
```

A priori aerodynamic information including matrix element positions and values
The default longitudinal AN matrix is

$$\begin{bmatrix} C_{L_\alpha} & C_{L_q} & 0 \\ C_{m_\alpha} & C_{m_q} & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

The default lateral AN matrix is

$$\begin{bmatrix} C_{Y_\beta} & C_{Y_p} & C_{Y_r} & 0 \\ C_{l_\beta} & C_{l_p} & C_{l_r} & 0 \\ C_{n_\beta} & C_{n_p} & C_{n_r} & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

The default longitudinal BN matrix is

$$\begin{bmatrix} C_{L_{\delta_e}} \\ C_{m_{\delta_e}} \\ 0 \end{bmatrix}$$

The default lateral BN matrix is

$$\begin{bmatrix} C_{Y_{\delta_a}} & C_{Y_{\delta_r}} \\ C_{l_{\delta_a}} & C_{l_{\delta_r}} \\ C_{n_{\delta_a}} & C_{n_{\delta_r}} \\ 0 & 0 \end{bmatrix}$$

```
CMA         LONG        AN(2,1)
   -.01912
CMQ         LONG        AN(2,2)
 -14.24700
CMAD        LONG        RN(2,1)
  -4.62511
CMDE        LONG        BN(2,1)
   -.03534
CNA         LONG        CN(4,1)
    .13165
CNQ         LONG        CN(4,2)
   5.77710
CNDE        LONG        DN(4,1)
    .01746
END
H1620035.OV3     16  TS1691 MMLE3 F111C LONG STAB P3F1E72 RUN 3 SLATS 35
FLAPS
 $USER LONG =T,
  KALF=1.06
   W=  69900.85930 ,CG=       .24468,
  IX= 73343.67180 ,IY= 344865.78100,
  IZ=411017.06200 ,IXZ=  3976.78710,
  XALF =  45.5107,   YALF =   .0000 , ZALF =   2.5535
  XB   =  44.7032,   YB   =   .0000 , ZB   =   3.0518
  XAX  =   2.5241,   YAX  = -2.4308 , ZAX  =   1.3877
```

```
 XAY  =   2.4216,   YAY  = -2.4583 , ZAY  =   1.3877
 XAN  =  20.6674,   YAN  =    .0000 , ZAN  =   1.6610
$END
```

Namelist INPUT is described in detail in Reference [15] section 3.3.8 with most of the variables being equal to a real or integer type number.

```
$INPUT CARD=T,NREC=24,ERRTH=F,
NUPLT=1,NEXPLT=6,
ERRMAX=10.E+30
TIMVAR=T,
SPS=60,TEST=F,
MZ=4,
MU=1,
MX=3,
NOITER=29,
ITG=30,
WAPR=1.0,
ITAPR=20,
ZSCALE(6)=57.295
ZSCALE(1)=1.0
$END
100000000 100006000
```

Some of the aerodynamic parameters are linked through hard constraints to reduce the number of independent variables and to improve the identification process. For the longitudinal motion the following constraints based on the *a priori* model values were used:

$$C_{m_{\dot{\alpha}}} = 0.32464 \times c_{m_q}$$

$$C_{l_q} = 330.86868 \times C_{n_{\delta_e}}$$

$$C_{L_{delta_e}} = C_{N_{delta_e}}$$

$$C_{L_\alpha} = C_{N_\alpha}$$

```
HARD     5

HARD     5
RN(2,1) = AN(2,2)  *     .32464
AN(1,2) = DN(4,1)  * 330.86868
CN(4,2) = DN(4,1)  * 330.86868
BN(1,1) = DN(4,1)  *1.0
```

```
AN(1,1) = CN(4,1)  *1.0
GGI      6
     10.     60.        0.        200.      0.0      100.
END
```

Flight data is provided in the following order:

$time, \alpha, q, V, \theta, a_n, \dot{q}, a_x, \delta_e, \delta_c, \delta_{1_{longitudinal}}, \delta_{2_{longitudinal}}, \phi, h, M, q, \beta, p, r, a_y, \dot{p}, \dot{r},$
$\delta_a, \delta_r, \delta_{1_{lateral}}, \delta_{2_{lateral}}$

```
100000000     2.5800     .0948  356.6570    1.1361    1.0559    1.5889
-.0336
   -4.4976     .0000     .0000     .0000   -1.6664 1198.0884     .3209
146.0993
     .2061   -1.1277    -.5927    -.0210    1.4067  -10.7151     .8083
-.5241
    -.6104
100000017     2.0532     .0423  356.2252    1.1361    1.0528    9.8155
-.0331
   -4.5087     .0000     .0000     .0000   -1.6664 1197.8882     .3206
145.7467
    -.0578   -1.1277    -.5927    -.0247    9.6135   -6.4547     .7972
-.4115
    -.6326
100000034     1.9216     .0948  356.6570    1.2242    1.0161    3.7826
-.0346
```

The results of the identification process are written into file FAR03.DAT and shown below are the results obtained after 12 iterations:

```
 WEIGHTED ERRORS
ERROR SUM =  3.0000
     ALPHA        Q          THETA       AN
    1.000       1.000       .0000       1.000

DET (RSQ) =  -3.494288
 AN                          3  BY  3
          .1202        6.509        .0000
        -.1916E-01   -27.80         .0000
          .0000        .0000        .0000
```

```
BN                          3  BY  1
          .2190E-01
         -.3045E-01
          .0000
SN                          3  BY  1
          .7031
         -.7449E-01
          .0000
          .0000
CN                          4  BY  3
          1.150       52.34       .0000
          .0000       1.000       .0000
          .0000       .0000       1.000
          .1302       6.509       .0000
DN                          4  BY  1
          .0000
          .0000
          .0000
          .2190E-01
HN                          4  BY  1
          .0000
          .0000
          .0000
          .7113
 WEIGHTED ERRORS
ERROR SUM =  2.9984
     ALPHA       Q           THETA       AN
    1.008       1.021       .0000       .9691

DET (RSQ) =  -3.485601
 GGI                        4  BY  4
          4.685       .0000       .0000       .0000
          .0000       1.185       .0000       .0000
          .0000       .0000       .0000       .0000
          .0000       .0000       .0000       434.5
ITERATION 12 COMPLETED. H1620035.OV3    16  TS1691 MMLE3 F111C LONG STAB
P3F1E72 RUN 3 SLATS 35 FLAPS

 COST FUNCTION CONVERGED WITHIN    .10E-02 BOUND.

 WEIGHTED ERRORS
ERROR SUM =  3.0000
```

```
     ALPHA          Q              THETA          AN
     1.000          1.000          .0000          1.000

DET (RSQ) =   -3.485601
CRAMER-RAO BOUNDS.

 AC                                  3   BY   3
             .0000          .0000              .0000
             .1363E-03      .7636              .0000
             .0000          .0000              .0000
 BC                                  3   BY   1
             .0000
             .3763E-03
             .0000
 SC                                  3   BY   1
             .8623E-02
             .1971E-02
             .0000
 CC                                  4   BY   3
             .0000          .0000              .0000
             .0000          .0000              .0000
             .0000          .0000              .0000
             .8890E-03      .0000              .0000
 DC                                  4   BY   1
             .0000
             .0000
             .0000
             .8654E-03
 HC                                  4   BY   1
             .0000
             .0000
             .0000
             .5932E-02
```

Appendix I - Longitudinal Equations of Motion

State variables $x = (\alpha, q, \theta)$

Control variables $u = (\delta_e)$

Observation variables $z = (\alpha_m, q_m, \theta_m, a_{n_m}, a_{x_m}, \dot{q}_m)$

The nonlinear longitudinal state equations are :

$$\begin{aligned}
\dot{\alpha} &= -\frac{\bar{q}S}{mV}R(C_L + \dot{\alpha}_0) + q + \frac{g}{V}R(\cos\theta\cos\alpha + \sin\alpha\sin\theta) \\
&\quad -\frac{T}{mV}R\sin\alpha \\
I_{yy}\dot{q} &= \bar{q}ScRC_m \\
\dot{\theta} &= q + \dot{\theta}_0
\end{aligned}$$

The $\dot{\alpha}_0$ and $\dot{\theta}_0$ are included to allow for instrument biases.

The longitudinal observation equations are :

$$\begin{aligned}
\alpha_m &= K_\alpha(\alpha - \frac{x_\alpha}{V}q) \\
q_m &= q \\
\theta_m &= \theta \\
a_{n_m} &= \frac{\bar{q}S}{mg}C_N + \frac{x_{a_n}}{gR}\dot{q} + \frac{z_{a_n}}{R^2g}q^2 \\
a_{x_m} &= -\frac{\bar{q}S}{mg}C_A + \frac{z_{a_x}}{gR}\dot{q} - \frac{x_{a_x}}{R^2g}q^2 + \frac{T}{mg} \\
\dot{q}_m &= \dot{q} + \dot{q}_0
\end{aligned}$$

The $\dot{q}_0$ is the instrument bias on $\dot{q}$.

The expansions of the longitudinal force and moment coefficients are :

$$
\begin{aligned}
C_N &= C_{N_\alpha}\alpha + C_{N_q}\frac{qc}{2VR} + C_{N_{\delta_e}}\delta_e + C_{N_0} \\
C_m &= C_{m_\alpha}\alpha + C_{m_q}\frac{qc}{2VR} + C_{m_{\delta_e}}\delta_e + C_{m_0} + C_{m_{\dot\alpha}}\frac{\dot\alpha c}{2VR} \\
C_A &= C_{A_\alpha}\alpha + C_{A_q}\frac{qc}{2VR} + C_{A_{\delta_e}}\delta_e + C_{A_0} \\
C_L &= C_N\cos\alpha - C_A\sin\alpha
\end{aligned}
$$

Appendix J - Lateral Equations of Motion

State variables	$x = (\beta, p, r, \phi)$
Control variables	$u = (\delta_a, \delta_r, \delta_{sp})$
Observation variables	$z = (\beta_m, p_m, r_m, \phi_m, a_{y_m})$

The nonlinear lateral-directional state equations are :

$$\begin{aligned}
\dot{\beta} &= \frac{\bar{q}S}{mV}R(C_Y + \dot{\beta}_0) + \frac{g}{V}R\cos\theta\sin\phi + p\sin\alpha - r\cos\alpha \\
\dot{p}I_x - \dot{r}I_{xz} &= \bar{q}SbRC_l + \frac{qr}{R}(I_y - I_z) + pq\frac{I_{xz}}{R} \\
\dot{r}I_z - \dot{p}I_{xz} &= \bar{q}SbRC_n + \frac{pq}{R}(I_x - I_y) - qr\frac{I_{xz}}{R} \\
\dot{\phi} &= p + r\cos\phi\tan\theta + q\sin\phi\tan\theta + \dot{\phi}_0
\end{aligned}$$

The terms $\dot{\beta}_0$ and $\dot{\phi}_0$ are included to allow for instrument biases.

The lateral observation equations are :

$$\begin{aligned}
\beta_m &= K_\beta(\beta - \frac{z_\beta}{V}p + \frac{x_\beta}{V}r) \\
p_m &= p \\
r_m &= r \\
\phi_m &= \phi \\
a_{y_m} &= \frac{\bar{q}S}{mg}C_Y - \frac{z_{a_y}}{gR}\dot{p} + \frac{x_{a_y}}{gR}\dot{r} - \frac{y_{a_y}}{R^2g}(p^2 + r^2) \\
\dot{p}_m &= \dot{p} + \dot{p}_0 \\
\dot{r}_m &= \dot{r} + \dot{r}_0
\end{aligned}$$

The terms $\dot{p}_0$ and $\dot{r}_0$ are the instrument biases on $\dot{p}$ and $\dot{r}$.

The expansions of the lateral force and moment coefficients are :

$$C_Y = C_{Y_\beta}\beta + C_{Y_p}\frac{pb}{2VR} + C_{Y_r}\frac{rb}{2VR} + C_{Y_\delta}\delta + C_{Y_0}$$

$$C_l = C_{l_\beta}\beta + C_{l_p}\frac{pb}{2VR} + C_{l_r}\frac{rb}{2VR} + C_{l_\delta}\delta + C_{l_0} + C_{l_{\dot\beta}}\frac{\dot\beta b}{2VR}$$

$$C_n = C_{n_\beta}\beta + C_{n_p}\frac{pb}{2VR} + C_{n_r}\frac{rb}{2VR} + C_{n_\delta}\delta + C_{n_0} + C_{n_{\dot\beta}}\frac{\dot\beta b}{2VR}$$

where the δ term is summed over all controls. For the 50° and 72.5° sweeps, the aileron (δ_a) and rudder (δ_r) are used. For sweeps less than or equal to 47°, the spoilers (δ_{sp}) are also operative.

Appendix K - Output File Notation

The notation for naming and cataloging MMLE3 results uses the following information: case type, sweep, altitude, Mach number and version.

$$\underbrace{A}_{casetype} \quad \overbrace{50}^{sweep} \quad \underbrace{H30}_{altitude} \quad \overbrace{M1.2}^{Machnumber} \quad \underbrace{V2}_{version}$$

Case type	A	Longitudinal MMLE3
	B	Lateral MMLE3
	C	Longitudinal MMLE3P
	D	Lateral MMLE3P
	E	Longitudinal MODEL
	F	Lateral MODEL

Where MMLE3 is the standard parameter estimation program. MMLE3P is a version with fixed weightings and MODEL contains the a priori results obtained from the six degree of freedom flight dynamic model of the F-111C.

sweep	16	16 degrees
	26	26 degrees
	35	35 degrees
	45	45 degrees
	50	50 degrees
	72	72.5 degrees

Height	H05	5000 feet
	H10	10000 feet
	H20	20000 feet
	H30	30000 feet
	H40	40000 feet
	H50	50000 feet

Version	longitudinal	
	1	Phase 1 +ve g pullup
	2	Phase 1 -ve g pushover
	3	Phase 2 +ve g pullup
	4	Phase 2 -ve g pushover
	5	Phase 1 +ve g pullup repeat
	6	Phase 1 -ve g pushover repeat
	7	Phase 2 +ve g pullup repeat
	8	Phase 2 -ve g pushover repeat
	lateral	
	1	Phase 1 initial roll to the right
	2	Phase 1 initial roll to the left
	3	Phase 2 initial roll to the right
	4	Phase 2 initial roll to the left
	5	Phase 1 initial roll to the right repeat
	6	Phase 1 initial roll to the left repeat
	7	Phase 2 initial roll to the right repeat
	8	Phase 2 initial roll to the left repeat

Longitudinal Analysis

Shown below is a typical longitudinal output file produced by MMLE3 with the following information:
File designation, title, flag to indicate C_{m_α} has been corrected for C of G position, actual sweep angle, actual Mach number, actual altitude, actual all up weight in pounds, C of G as a % of mean aerodynamic chord.

```
A50H30M1.2V2     50 TS1691 MMLE3 F111C LONG STAB L8E01 RUN 8_NG
CMACORR 50         +1.2287 +30076.6113 +74812.6250     +0.2978
```

Estimates for the longitudinal stability and control derivatives are presented followed by their Cramer-Rao bounds.

$$\begin{bmatrix} C_{L_\alpha} & C_{L_q} \\ C_{m_\alpha} & C_{m_q} \\ C_{m_{\dot\alpha}} & \\ C_{L_{\delta_e}} & C_{m_{\delta_e}} \end{bmatrix}$$

```
+0.0747      +5.7827
-0.0565     -17.0710
```

```
-3.2007
+0.0107      -0.0264
+0.0007      +0.0000
+0.0001      +0.2888
+0.0000
+0.0004      +0.0001
```

The last line contains the weightings for the output variables α, q, θ, a_n used in the cost function equation.

```
+23.2331     +16.0489     +0.0000   +1081.3801
```

Lateral Analysis

Shown below is a typical lateral output file produced by MMLE3 with the following information:
File designation, title, actual sweep angle, actual Mach number, actual altitude, actual all up weight in pounds.

```
D72h20m1.5v2     72.5     p1f11e4a
 72.5                +1.52387714        +20536.5234         +72698.5
```

Estimates for the lateral stability and control derivatives are presented followed by their Cramer-Rao bounds.

$$\begin{bmatrix} C_{Y_\beta} & C_{Y_p} & C_{Y_r} \\ C_{l_\beta} & C_{l_p} & C_{l_r} \\ C_{n_\beta} & C_{n_p} & C_{n_r} \\ C_{Y_{\delta_a}} & C_{Y_{\delta_r}} & C_{Y_{\delta_{sp}}} \\ C_{l_{\delta_a}} & C_{l_{\delta_r}} & C_{l_{\delta_{sp}}} \\ C_{n_{\delta_a}} & C_{n_{\delta_r}} & C_{n_{\delta_{sp}}} \end{bmatrix}$$

```
-8.48778523E-03  -3.59000004E-02  +0.285699993
-6.61816797E-04  -4.74088229E-02  +2.65999995E-02
+6.76631927E-04  +2.00000009E-03  -0.184223115
+1.58686505E-03  +7.39969196E-04  +0.0
-8.60938453E-04  +4.41243264E-06  +0.0
-1.13605608E-04  -4.27318154E-04  +0.0
+1.06449871E-04  +0.0             +0.0
+8.6396003E-06   +4.21156204E-04  +0.0
```

+5.87599834E-06	+0.0	+2.9275713E-03
+4.32894958E-05	+8.66981717E-05	+0.0
+3.71340024E-06	+6.69186238E-06	+0.0
+2.76041328E-06	+5.60222906E-06	+0.0

The last line contains the weightings for the output variables β, p, r, ϕ and a_y in the cost function equation.

+6.00899982	+0.400000005	+15.0	+0.0	+15000.0

Take-Off and Landing Analysis

The notation for the take-off and landing configuration is as follows:

$$\underbrace{H}_{casetype}\quad \overbrace{16}^{sweep}\quad \underbrace{240}_{VIASknots}\quad \overbrace{25.0}^{flapsetting}\quad \underbrace{V1}_{version}$$

Case type	H	Longitudinal MMLE3
	I	Lateral MMLE3
	J	Longitudinal MMLE3P
	K	Lateral MMLE3P
	L	Longitudinal MODEL
	M	Lateral MODEL
VIAS	150	150 knots indicated
	160	160 Knots indicated
	180	180 Knots indicated
	200	200 Knots indicated
	215	215 Knots indicated
	240	240 Knots indicated
Flap setting	00	0 flaps, slats extended
	15	15 degrees flap, slats extended
	25	25 degrees flap, slats extended
	35	35 degrees flap, slats extended

Version designation is identical for the clean aircraft configuration and the take off and landing configuration.

Table 1: **Instrumentation Channels used for Flight Dynamic Analysis**

Quantity	Symbol	Units	Range	Accuracy
ACCEL LONG CG*	a_x	g	±5	±0.05
ACCEL LAT CG	a_y	g	±5	±0.05
ACCEL VERT CG*‡	a_z	g	±10	±0.05
ROLL RATE	p	deg/sec	±300	±3
PITCH RATE	q	deg/sec	±100	±1
YAW RATE	r	deg/sec	±50	±0.5
ROLL ACC CG	$\dot{p}$	rad/sec^2	±10	±0.05
PITCH ACC CG	$\dot{q}$	rad/sec^2	±5	±0.05
YAW ACC CG	$\dot{r}$	rad/sec^2	±5	±0.05
ROLL ANGLE	ϕ	deg.	±180	±0.5
PITCH ANGLE	θ	deg.	±180	±0.5
ANGLE OF ATTACK*	α	deg.	$-3 \rightarrow 25$	±0.5
ANGLE OF SIDESLIP*	β	deg.	±24	±0.5
VELOCITY	V	kt.	$0 \rightarrow 900$	±10
MACH No.†	M	–	$0.3 \rightarrow 1.8$	±0.001
ALTITUDE†	H	ft.	$-500 \rightarrow 55000$	±1.5
WING SWEEP	Λ	deg.	$16 \rightarrow 72.5$	±0.05
STABILATOR (right)	δ_{e_R}	deg.	$-30 \rightarrow 15$	±0.1
STABILATOR (left)	δ_{e_L}	deg.	$-30 \rightarrow 15$	±0.1
RUDDER	δ_r	deg.	±30	±0.1
SPOILER (right)	δ_{sp_R}	deg.	$0 \rightarrow 45$	±0.1
SPOILER (left)	δ_{sp_L}	deg.	$0 \rightarrow 45$	±0.1
STICK POS (long)		in.	$-4.4 \rightarrow 3.6$	±0.05
STICK POS (lat)		in.	±5	±0.05
RUDDER PED POS		in.	±3	±0.03

* NBTU measurements available in Phase 2

† Altitude and Mach no. coarse and fine readings available

‡ Crew module normal accelerometer used in flights 2 and 3 of Phase 2 because of a fault in the CG accelerometer signal

Table 2: **Matrix of Test Points for Phase 1 and Phase 2**

ALT. ft.	Λ°	MACH NUMBER 0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
5000	26	●●	●	○	●	○										
	35	○	●	○	●	○										
	45		●	○	●	○	○									
	50			○●●	●	○	○		●	●						
	72.5			○	●	○	○		●	○○						
10000	16	○	●	○												
	26	○	●	●	●	●										
	35	○	●	●	●	●										
	45		●	●	●	●	●	○○								
	50			●	●	●	●	○○		○○		●●				
	72.5			●	●	●	●	○○		○●●		●●				
20000	16	○	●●	○●●	●	○										
	26	○	●	○	●	○										
	35		●	○	●	○●●										
	45			○	●	○	○●●		●							
	50			○	●	○	●●		●	○●		●				
	72.5				●	○	○		●	○			○			
30000	16			○●	●	○										
	26			○●	●	○	●									
	35			○	●	○	●									
	45				●	○	●	○	●							
	50				●	○	●	○		○		●	○			
	72.5						○	○		●		●	○			
40000	35					○	●	●								
	45						○	●								
	50						○		●	○●			○			○○
	72.5								●	○			○			○○
50000	50															○
	72.5															○

○ – Phase 1
● – Phase 2

Table 3: **Take-Off and Landing Aircraft Configurations**

Manoeuvre	Phase	Altitude (ft.)	Mach no./ KCAS	Sweep (deg.)
Landing Configuration				
15° flap	1	1000	177 kn.	16
			188 kn.	23
			236 kn.	16
			238 kn.	23
34° flap	2	1000	200 kn.	16
			160 kn.	26
35° flap	1	1000	147 kn.	16
			150 kn.	20
Slats, no flap	1	1000	198 kn.	16
			215 kn.	25
			240 kn.	16
				26
Take Off Configuration				
25° flap	1	1000	158 kn.	16
	2	1000	165 kn.	16

Table 4: **Supplementary Manoeuvres**

Manoeuvre	Phase	Altitude (ft.)	Mach no./ KCAS	Sweep (deg.)
Roller Coaster	1	4000	0.60	30
		5000	0.60	30
			0.80	56
		10000	0.80	55
			1.20	72.5
	2	10000	0.70	35
Lateral Oscillations	1	1000	0.40	16
		2000	143 kn.	16
		5000	0.60	30
			0.80	56
		10000	0.80	55
		20000	1.20	54
Dutch Roll	2	10000	0.60	26
			0.70	26
			0.70	35
			0.70	45
		20000	0.65	26
			0.74	26
Steady Heading Sideslip				
Right	2	10000	0.60	26
Left	2	10000	0.60	26
Steady Level Trim	2	10000	0.60	26

Table 5: **Weighing Information for Phase 1 Aircraft , 16° Sweep Flaps Down**

Configuration

Wing Sweep:	16 Degrees
Flaps:	Fully extended
Slats:	Fully extended
Gear :	Down

Support Points	Weight (lb)
Port	22208
Starboard	22357
Nose	6108

Support Point Total	Weight (lb)	Arm (in)	Moment (lb-in)
Main	44565	561.4	25018791
Nose	6108	264.8	1617398
Total	50673	525.6	26636189

Table 6: **Weighing Information for Phase 1 Aircraft , 16° Sweep**

Configuration

Wing Sweep:	16 Degrees
Flaps:	Up
Slats:	Up
Gear :	Down

Support Points	Weight (lb)
Port	22207
Starboard	22242
Nose	6158

Support Point Total	Weight (lb)	Arm (in)	Moment (lb-in)
Main	44449	561.4	24953669
Nose	6158	264.8	1630638
Total	50607	525.3	26584307

Table 7: **Weighing Information for Phase 1 Aircraft , 26° Sweep**

Configuration

Wing Sweep:	26 Degrees
Flaps:	Up
Slats:	Up
Gear :	Down

Support Points	Weight (lb)
Port	22445
Starboard	22539
Nose	5713

Support Point Total	Weight (lb)	Arm (in)	Moment (lb-in)
Main	44984	561.4	25254018
Nose	5713	264.8	1512802
Total	50697	528.0	26766820

Table 8: **Weighing Information for Phase 1 Aircraft , 35° Sweep**

Configuration

Wing Sweep:	35 Degrees
Flaps:	Up
Slats:	Up
Gear :	Down

Support Points	Weight (lb)
Port	22631
Starboard	22776
Nose	5233

Support Point Total	Weight (lb)	Arm (in)	Moment (lb-in)
Main	45407	561.4	25491489
Nose	5233	264.8	1385698
Total	50640	530.8	26877188

Table 9: **Weighing Information for Phase 1 Aircraft , 50° Sweep**

Configuration

Wing Sweep: 50 Degrees
Flaps: Up
Slats: Up
Gear : Down

Support Points	Weight (lb)
Port	22631
Starboard	22776
Nose	5233

Support Point Total	Weight (lb)	Arm (in)	Moment (lb-in)
Main	45407	561.4	25491489
Nose	5233	264.8	1385698
Total	50640	530.8	26877188

Table 10: **Weighing Information for Phase 2 Aircraft , 26° Sweep**

Configuration

Wing Sweep: 26 Deg
Flaps: Up
Slats: Up
Gear : Down
NBTU installed

Support Points	Weight (lb)
Port	22199
Starboard	22321
Nose	6555

Support Point Total	Weight (lb)	Arm (in)	Moment (lb-in)
Main	44520	562.64	25048732
Nose	6555	269.55	1766900
Misc.	23		16998
Total	51098	524.8	26817331

Note :

Misc. refers to an adjustment that has to be made to the final weight and moment arm of the aircraft to compensate for

- Any items weighed but are not part of the basic configuration .
- Items that are part of the basic configuration that were not in the aircraft when it was weighed.

Table 11: **Instrumentation Lags**

Channel	Phase 1	Phase 2
δ_{stab_R}	0	0
δ_{stab_L}	0	0
δ_r	0	0
$\delta_s p_R$	0	0
$\delta_s p_L$	0	0
α	2	-2
β	0	0
θ	0	-2
ϕ	0	0
p	2	2
q	3	3
r	2	2
$\dot{q}$		3
a_n	4	4
$a_{n_{CM}}$		0

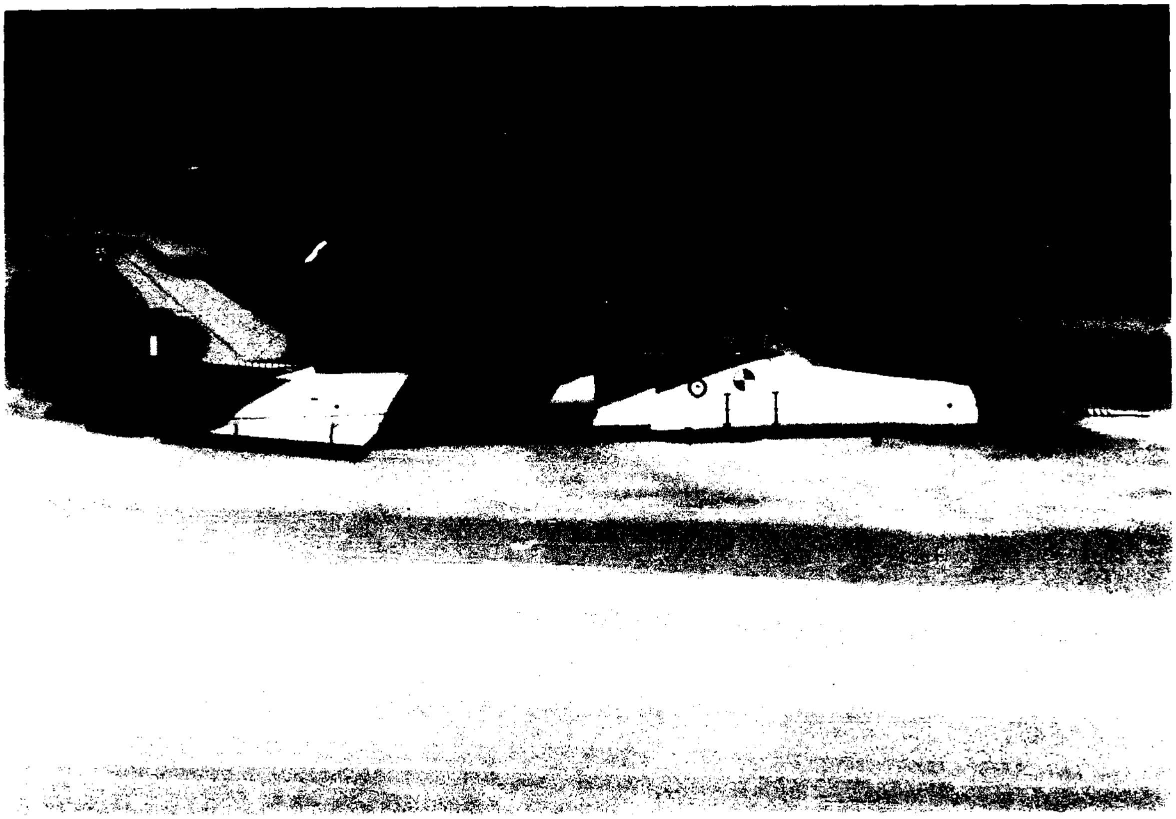


Figure 1: **Instrumented F-111C Aircraft (A8-132) Operated by ARDU for Flight Trial**

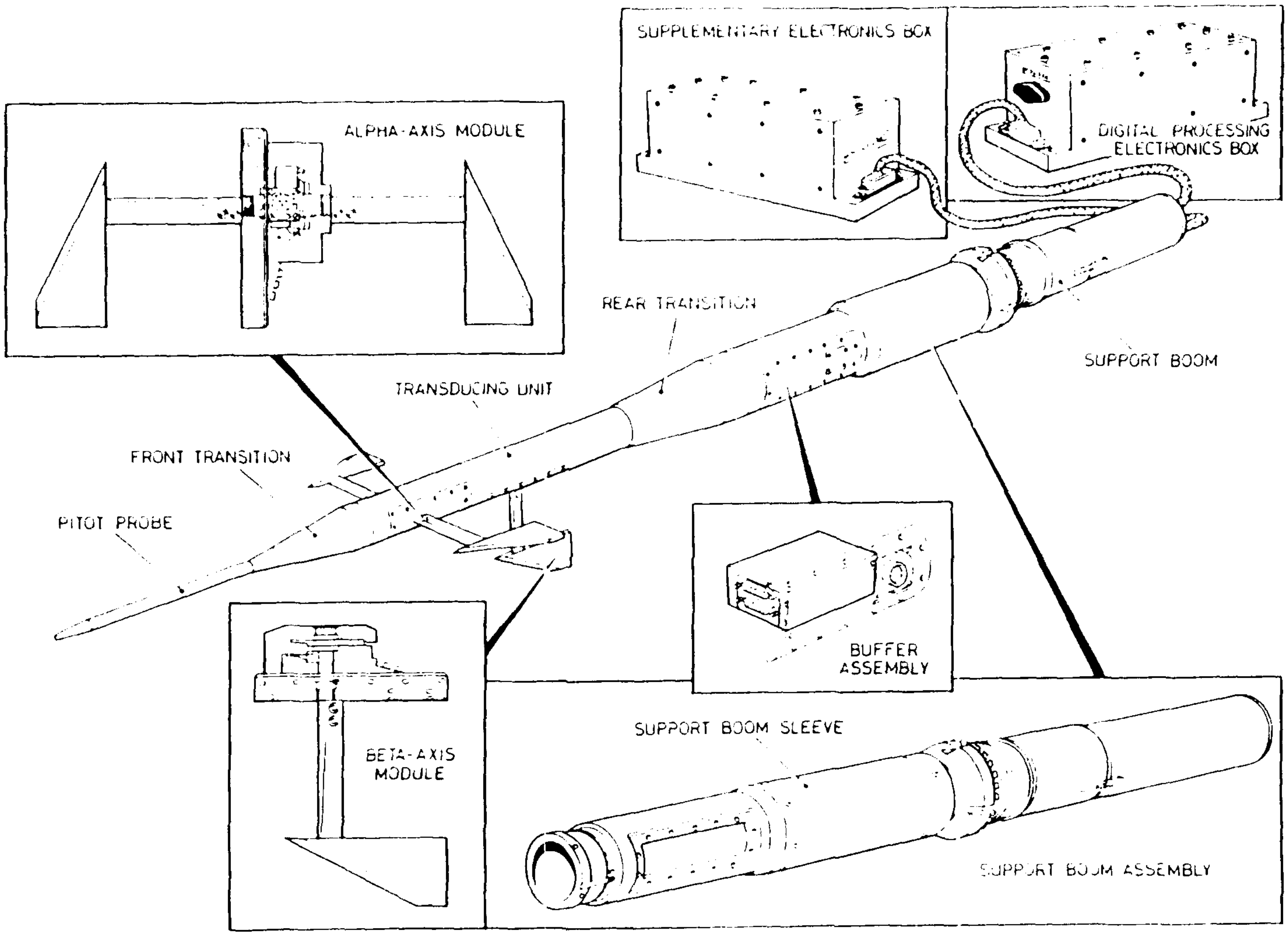


Figure 2: **Nose Boom Transducing Unit (from Ref. [1])**

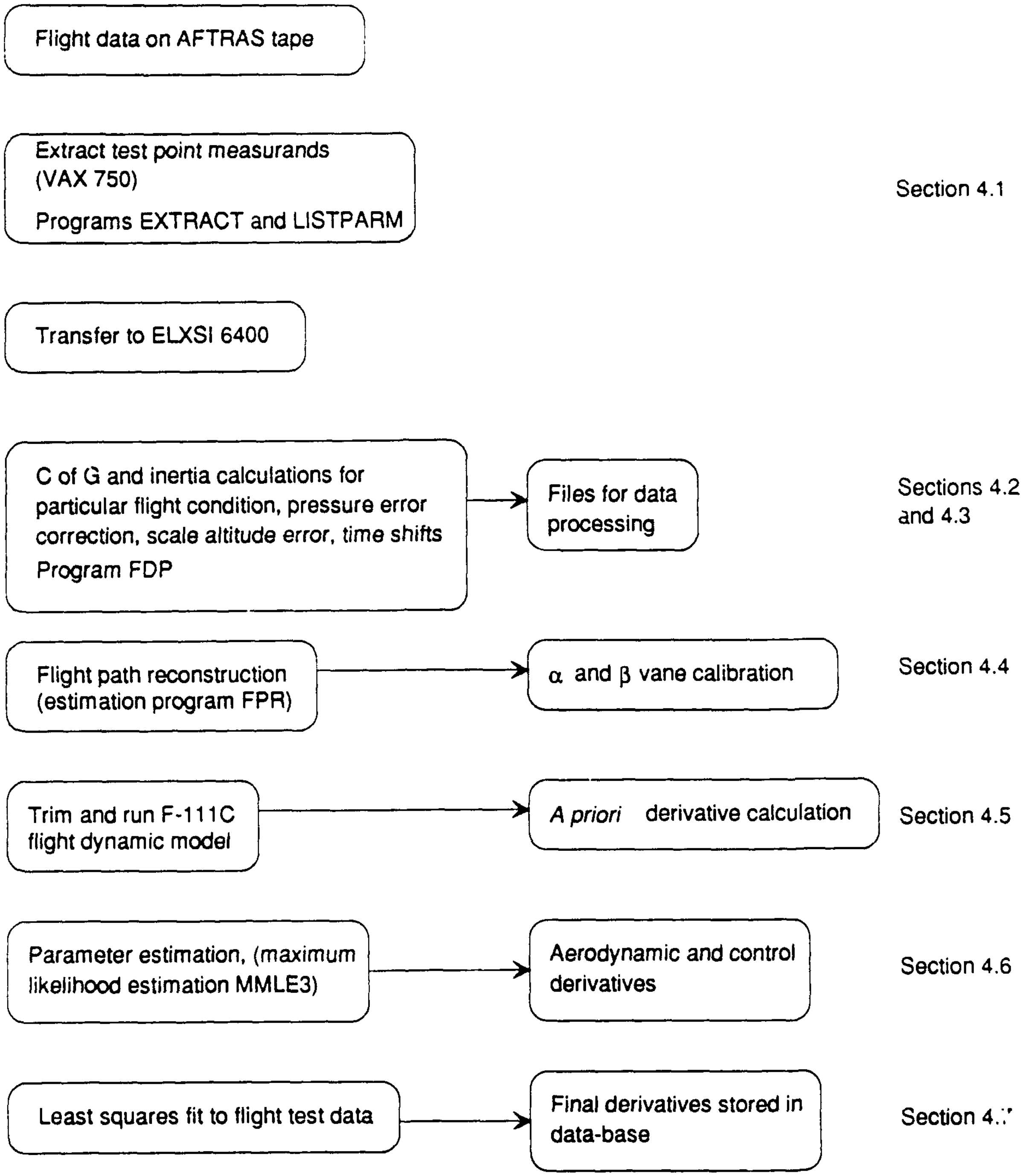


Figure 3: Summary of Flight Data Processing and Analysis Procedures

	INPUT FILES	PROGRAMS	OUTPUT FILES
VAX 750	INDATA.DAT	EXTRACT	OUTPUT.DAT
VAX 750	OUTPUT.DAT	LISTPARM	LISTPARM.DAT
ELXSI	LISTPARM.DAT	TRPLOT	PLOTS.DAT
ELXSI	PLOTS.DAT	TRANS	PLOTS.PL0
ELXSI	DATABASE CGTABLE	CGCALC_P1OR3	MMLE3.PARA
ELXSI	LISTPARM.DAT	FDP	F111C.DAT FPR.LON FPR.LAT MMLE3.DAT
ELXSI	DATIN.ALL DATIN.DAT	FPRSORT	DATIN.OUT
ELXSI	DATIN.OUT	FPR	FLINP.DAT FPRTOMMLE3 PREOUT FLI1A.DAT STATE.DAT COMPAT.DAT

Figure 4: Summary of Computer Programs, Input and Output File Names

	INPUT FILES	PROGRAMS	OUTPUT FILES
ELXSI	STATE.DAT FLI1A.DAT COMPAT.DAT	FPRPLOT	METADAT
	TABLEE.NEW SETUP F111LONGDB F111LATDB F111TOLADB	F111LATLONG	F111DERV METADAT F111LATLONG.L
	FAR01.DAT	MMLE3	FOR03.DAT METADAT 'RESULTFILE'
PS2	'RESULTFILE'	F111	'RESULTFILE'.DAT 'RESULTFILE'.GRF 'RESULTFILE'.PRN

Figure 5: **Summary of Computer Programs, Input and Output File Names (continued)**

AIRCRAFT RESEARCH AND DEVELOPMENT UNIT				
TS ~~FF~~ No	FLT No	A/C No	DATE	PILOT
1691	Ser 6	A8-132	18 FEB 87	

							FUEL		GAINS	
Ser	[illegible]	Ev	ALT	IMN	KCAS	α	FWD	AFT	P	R
			Pitch	Doublets						
1	2	1 A	40K	0.9	274	50	16.8	8 2	95	100
		2								
		3 F								
		4.	✓	✓	✓	✓	✓	✓	✓	✓
			Roll	Inputs						
2.	3	5 L	40K	0.9	✓	50	✓	✓	100	100
		6								
		7 R								
		8.	✓	✓	✓	✓	✓	✓	✓	✓
			Pitch	Doublets						
3	4	9 A	40K	0.9	274	45	16.4	7.9	100	100
		10								
		11 F								
		12	✓	✓	✓	✓	✓	✓	✓	✓
			Roll	Inputs.						
4	5	13 L	40K	0.9	✓	45	✓	✓	✓	[illegible]
		14								
		15 R								
		16	✓	✓	✓	✓	✓	✓	✓	✓

Figure 6: Typical Pilot's Test Card

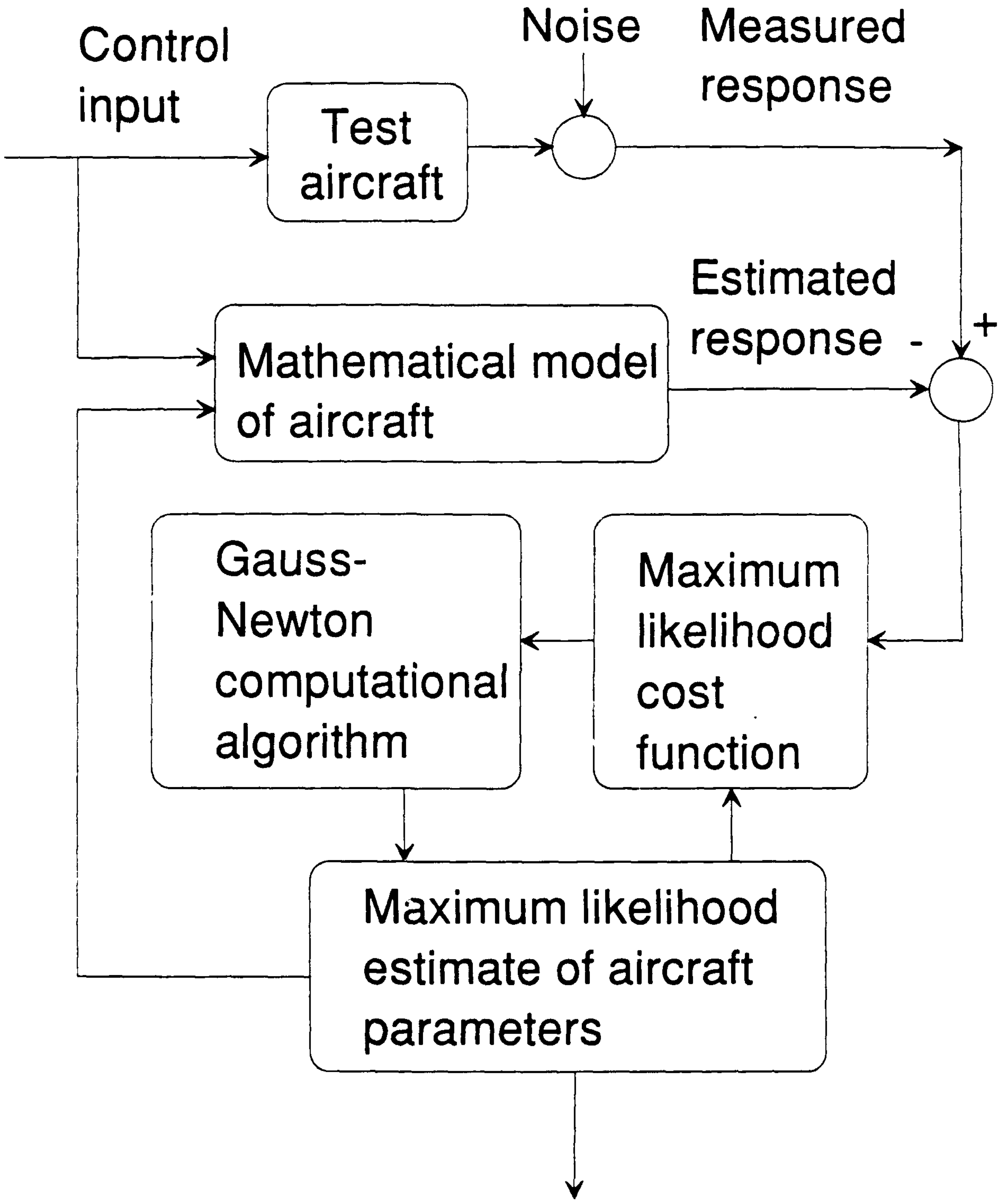


Figure 7: Block Diagram of Maximum Likelihood Estimation Procedure

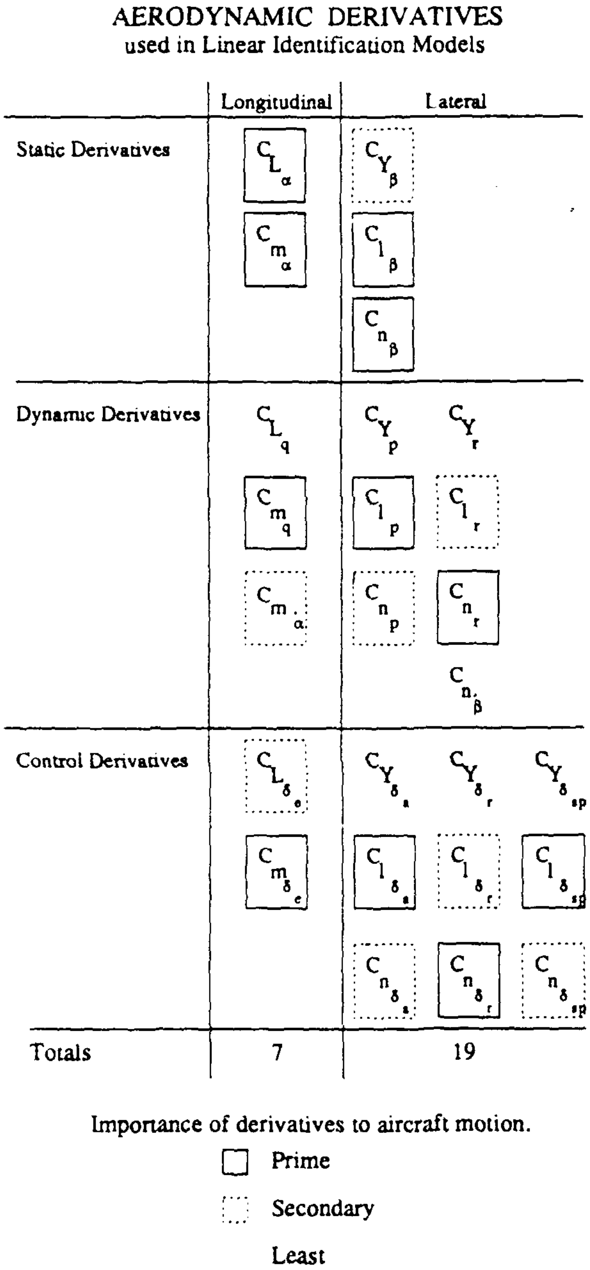


Figure 8: **Summary of Aerodynamic Parameters Used in Linear Identification Models**

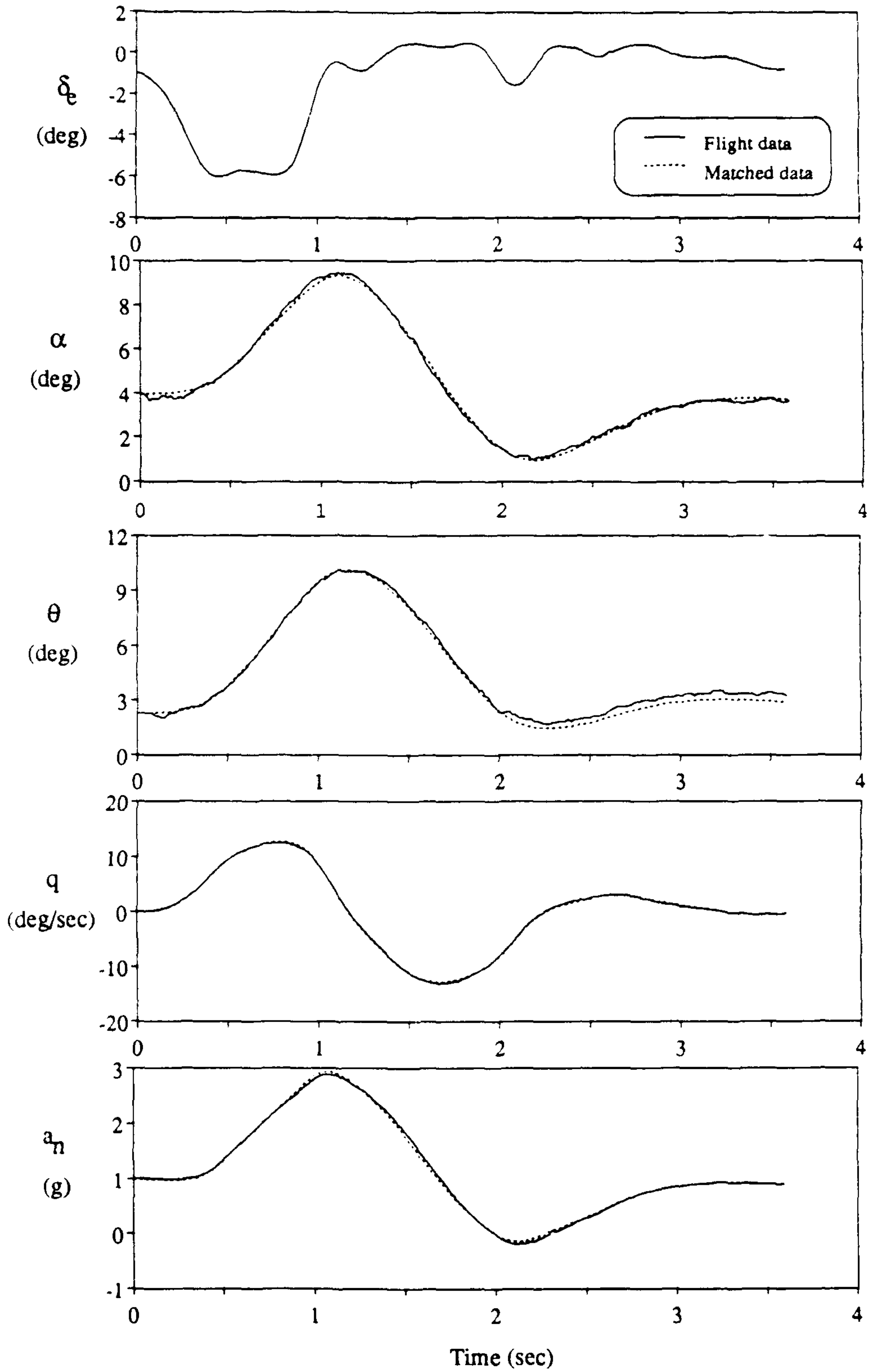


Figure 9: **Example Time Histories for Longitudinal Manouevres**

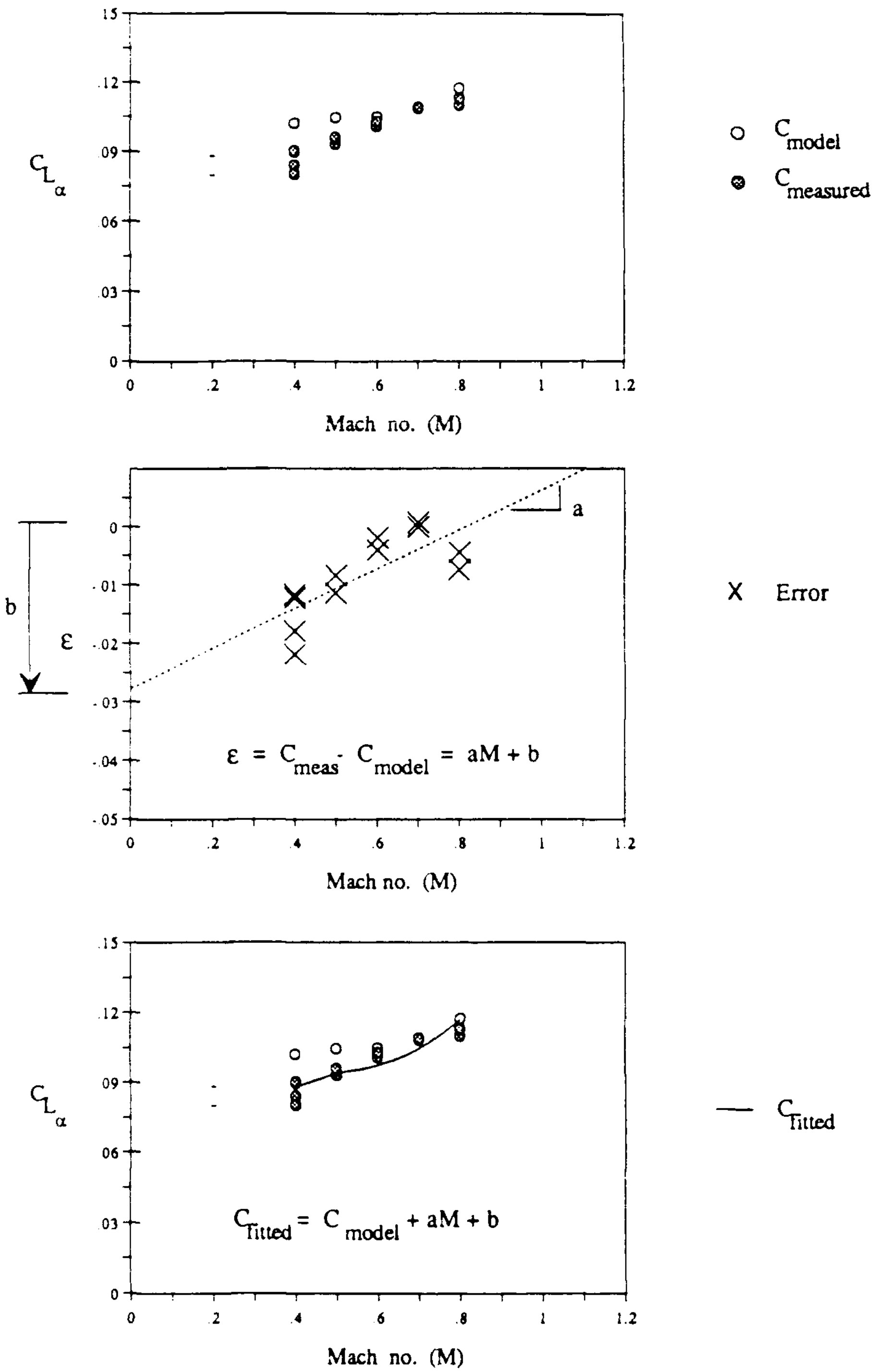


Figure 10: **Curve Fitting Procedure for Derivatives**

DISTRIBUTION

AUSTRALIA

<u>Department of Defence</u>

<u>Defence Central</u>

Chief Defence Scientist
FAS Science Policy (shared copy)
Science Corporate Management (shared copy)
Counsellor, Defence Science, London (Doc Data sheet Only)
Counsellor, Defence Science, Washington (Doc Data sheet Only)
Document Exchange Centre, DISB (8 copies)
OIC TRS, Defence Central Library
Joint Intelligence Organisation
Librarian H Block, Victoria Barracks, Melbourne

<u>Aeronautical Research Laboratory</u>

Director
Library
Chief of Flight Mechanics and Aircraft Propulsion
Branch Head .. Flight Mechanics
Branch File .. Flight Mechanics
Authors: M. I. Cooper
J. S. Drobik
C. A. Martin
L. D. MacLaren
P. W. Gibbens
S. D. Hill
J. L. Gray
R. A. Feik
A. M. Arney

<u>Materials Research Laboratory</u>

Director / Library

Weapon Systems Research Laboratory

Combat Systems Division

Defence Science and Technology Organisation - Salisbury

Library

Navy Office

Navy Scientific Adviser (3 copies Doc Data sheet only)
Aircraft Maintenance and Flight Trials Unit
RAN Tactical School, Library
Director of Naval Aircraft Engineering
Director of Naval Air Warfare
Superintendent, Aircraft Maintenance and Repair

Army Office

Scientific Adviser - Army (Doc Data sheet only)
US Army Research, Development and Standardisation Group

Air Force Office

Airforce Scientific Advisor
Engineering Branch Library
Director General Engineering - Air Force
Director General Force Development - (Air)
HQ Air Command (SMAINTSO)
HQ Air Command (INT1)
HQ Logistics Command (DGLOGENG)
HQ Logistics Command (AEENG1)
Aircraft Research and Development Unit
Flight Test Squadron
Library

RAAF Base Amberley
CO 82 Wing
1 Sqn, CO
6 Sqn, CO
482 Sqn, CO

Statutory and State Authorities and Industry

Aero-Space Technologies Australia, Manager/Librarian (2 copies)
AWA Defence and Aerospace, Victoria
Qantas Airways Limited
Australian Airline, Library
Ansett Airlines of Australia, Library
Hawker de Havilland Aust Pty Ltd, Victoria, Library
Hawker de Havilland Aust Pty Ltd, Bankstown, Library
Rolls Royce of Australia Pty Ltd, Manager

Universities and Colleges

Adelaide
Barr Smith Library

Flinders
Library

La Trobe
Library

Melbourne
Engineering Library

Monash
Hargrave Library

Newcastle
Library (2 copies)

New England
Library

NSW
Physical Sciences Library
Head, Mechanical Engineering
Head, Fluid Technology
Library, Australian Defence Force Academy

Queensland
Library

RMIT
Library
Mr. R. Dengate, Aerospace Engineering

Sydney
Engineering Library

Tasmania
Engineering Library

University College of the Northern Territory
Library

Western Australia
Library
Professor B.J. Stone, Head Mechanical Engineering

SPARES (10 copies)

TOTAL (90 copies)

AL 149 DEPARTMENT OF DEFENCE

DOCUMENT CONTROL DATA

PAGE CLASSIFICATION
UNCLASSIFIED

PRIVACY MARKING

1a. AR NUMBER	1b. ESTABLISHMENT NUMBER	2. DOCUMENT DATE	3. TASK NUMBER
AR-005-639	ARL-FLIGHT-MECH-R-187	DECEMBER 1990	AIR 85/128

4. TITLE
F-111C FLIGHT DATA REDUCTION AND ANALYSIS PROCEDURES

5. SECURITY CLASSIFICATION (PLACE APPROPRIATE CLASSIFICATION IN BOX(S) IE. SECRET (S), CONF (C) RESTRICTED (R), UNCLASSIFIED (U))

DOCUMENT	TITLE	ABSTRACT
U	U	U

6. NO. PAGES
83

7. NO. REFS
22

8. AUTHOR(S)
M.I. COOPER
J.S. DROBIK
C.A. MARTIN

9. DOWNGRADING/DELIMITING INSTRUCTIONS
Not applicable

10. CORPORATE AUTHOR AND ADDRESS
AERONAUTICAL RESEARCH LA RATORY
506 LORIMER STREET
FISHERMENS BEND VIC 3207

11. OFFICE/POSITION RESPONSIBLE FOR
SPONSOR RAAF
SECURITY -
DOWNGRADING -
APPROVAL DARL

12. SECONDARY DISTRIBUTION (OF THIS DOCUMENT)
Approved for public release

OVERSEAS ENQUIRIES OUTSIDE STATED LIMITATIONS SHOULD BE REFERRED THROUGH DSTIC, ADMINISTRATIVE SERVICES BRANCH, DEPARTMENT OF DEFENCE, ANZAC PARK WEST OFFICES, ACT 2601

13a. THIS DOCUMENT MAY BE ANNOUNCED IN CATALOGUES AND AWARENESS SERVICES AVAILABLE TO
No limitations

13b. CITATION FOR OTHER PURPOSES (IE. CASUAL ANNOUNCEMENT) MAY BE [X] UNRESTRICTED OR [ ] AS FOR 13a.

14. DESCRIPTORS	15. DISCAT SUBJECT CATEGORIES
Aerodynamics	010303
F-111C aircraft	010101
Flight dynamics	0104
Flight tests	0101
Parameter estimation	

16. ABSTRACT
A series of flight trials was performed on the F-111C aircraft at the RAAF's Aircraft Research and Development Unit in February and October 1987. Data obtained from the tests were analysed at the Aeronautical Research Laboratory to determine the aircraft aerodynamic and control derivatives. This report describes the methods and computer programs which are used to process and analyse the flight test data. Data handling procedures, pre-analysis flight data processing and the methods used to make corrections to air sensor measurements are described. Although the test programme was conducted on a F-111C aircraft, with minor alterations the computer programs and procedures can be used for other aircraft test programmes.

PAGE CLASSIFICATION
UNCLASSIFIED

PRIVACY MARKING

THIS PAGE IS TO BE USED TO RECORD INFORMATION WHICH IS REQUIRED BY THE ESTABLISHMENT FOR ITS OWN USE BUT WHICH WILL NOT BE ADDED TO THE DISTIS DATA UNLESS SPECIFICALLY REQUESTED.

16. ABSTRACT (CONT)

17. IMPRINT

AERONAUTICAL RESEARCH LABORATORY, MELBOURNE

18. DOCUMENT SERIES AND NUMBER	19. COST CODE	20. TYPE OF REPORT AND PERIOD COVERED
FLIGHT MECHANICS REPORT 187	52-5070	

21. COMPUTER PROGRAMS USED

22. ESTABLISHMENT FILE REF.(S)

23. ADDITIONAL INFORMATION (AS REQUIRED)